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U. S. NAVY BATTLE DAMAGE PICTURES FROM WORLD WAR II.

BY COMMANDER ERNEST C. HOLTZWORTH, U. S. NAVY.

PART 3

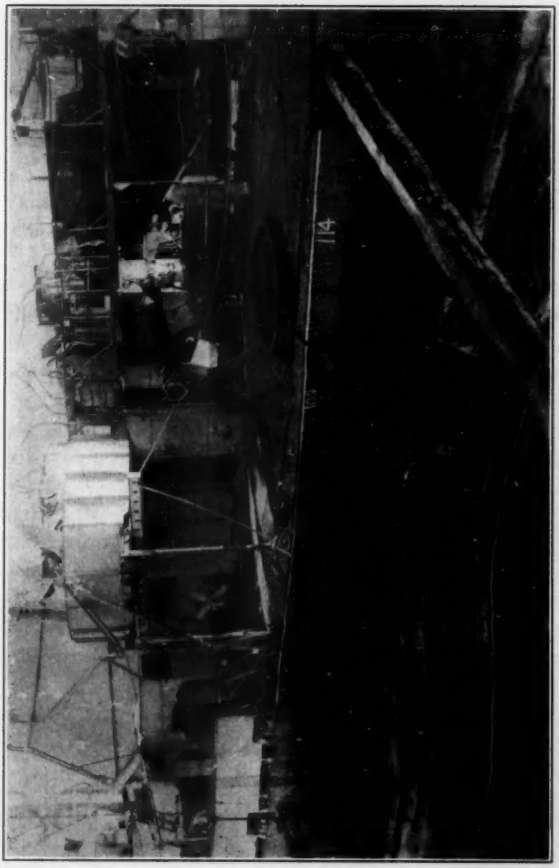
The following photographs comprise the third of four series which the Society is publishing in consecutive issues of the JOURNAL. They have been selected from those in the files of the Bureau of Ships, Navy Department, and all are official U. S. Navy Photographs. They portray typical examples of damage incurred by U. S. warships in action against the enemy. A brief description of the circumstances in each case is included with the caption.

Photo 1: The U.S.S. *Mayrant* (DD402) in drydock at Malta, about 11 August, 1943. She was damaged on 26 July, 1943, while on patrol off the harbor of Palermo, Sicily. A close near-miss bomb detonated well below the water surface abreast the port side amidships and caused the damage shown in the photo.

The contours of damage to the hull indicate that the bomb detonated very close to the shell at a point slightly above the turn of the bilge. Although the shell was not demolished, there were a number of transverse cracks, as shown in the photo, and longitudinal seam rips. The forward engineroom and after fireroom flooded immediately, the after engineroom flooded somewhat more slowly and the forward fireroom still more slowly. Flooding of the latter space was controlled finally with the water level about four feet below the external waterline.

U. S. Navy divers at Palermo installed crude patches sufficiently effective to permit dewatering of all four spaces by salvage pumps. *Mayrant* then was towed to Malta for drydocking. A temporary patch, consisting of shell wrapper plates and heavy external longitudinals, was installed in one of the outstanding repair jobs of the war. After reconditioning of machinery, she crossed the Atlantic to Navy Yard, Charleston. Enroute, she successfully weathered a heavy storm.

Mayrant was one of the few U. S. warships damaged seriously during the war by close near-miss bombs.



U. S. S. "Mayrant" (DD402).

Photo 2: The U.S.S. *Marblehead* (CL12) in drydock at Tjilatjap, Java early in February, 1942. The photo shows damage to the shell caused by a close near-miss bomb.

Marblehead was damaged off the western end of Java on 4 February, 1942, during the course of a sustained Japanese air Attack. In addition to the near-miss damage in the photo, she also was struck by two bombs which inflicted further damage.

The near-miss bomb detonated close under the turn of the bilge some 100 feet aft of the stem on the port side. The shell was sharply indented with a hole about 10 feet in diameter in the center of the indentation. Tears and rips, radiating fore and aft from the hole, in the bottom permitted extensive flooding forward. She increased trim by the bow more than 11 feet. This was reduced partially by flooding of a few stern compartments—the result of a bomb hit well aft.

She proceeded to Tjilatjap where the one small floating drydock did not permit lifting her clear of the water, thus preventing the extensive repairs required. She next went to Ceylon, thence to Durban and then stopped at Simon's Town, Union of South Africa, where she was drydocked again and the repairs required for a trans-atlantic crossing accomplished. She then steamed to Navy Yard, New York, via Pernambuco, Brazil.

Marblehead's near-miss damage, as was *Mayrant's,* was among the most serious cases of such suffered by U. S. warships during the war.

U. S. S. "MARBLEHEAD" (CL12).

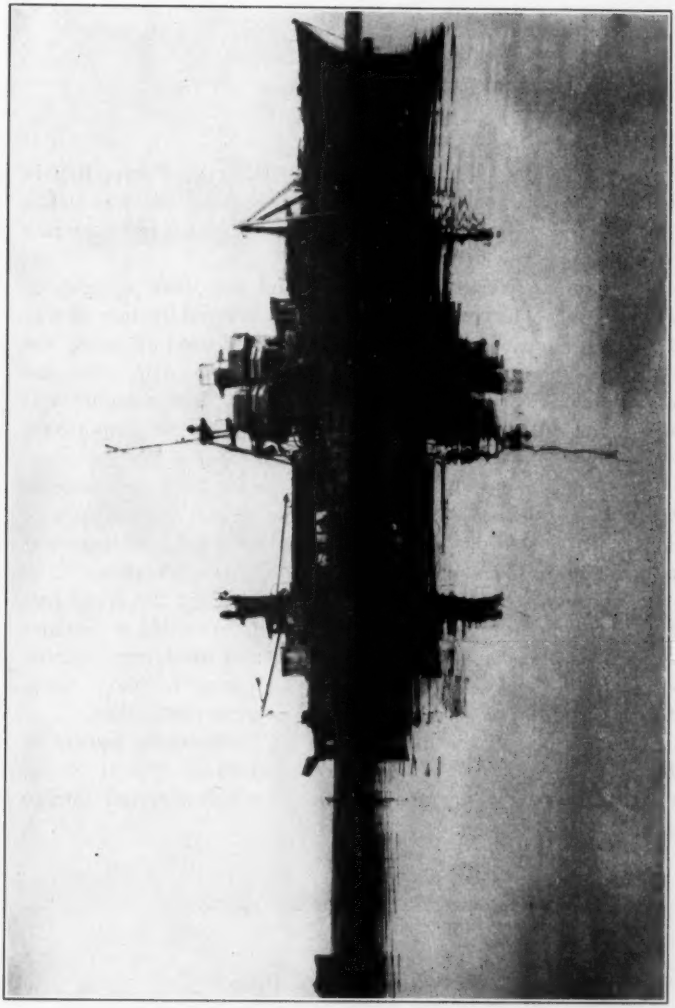
Photo 3: The U.S.S. *Erie* (PG50) moored at Willemstad, N.W.I., on 2 December, 1942. The damage to the hull, discernible on the starboard quarter, was the result of a German submarine torpedo.

Erie was torpedoed on 12 November, 1942, while a unit of a convoy escort. The torpedo struck the starboard quarter in way of her aviation gasoline tanks (she was carrying one search plane), rupturing them and spreading gasoline throughout the after portion of the ship. Engulfed in flames and with her stern low in the water, she was beached not far from Willemstad.

The fire, fanned by a brisk breeze from astern, gutted *Erie*. It was fed not only by gasoline but also by oil from ruptured fuel tank. It quickly consumed ready-service ammunition and the one plane. Only the machinery spaces and the forward lower magazines escaped the flames.

She was floated successfully and towed to Willemstad where the photo was taken. Salvage efforts leading to temporary repairs for her return to the United States were underway (note the salvage barge alongside in the photo) when she capsized at her moorings during the night of 4-5 December, 1942.

Erie's fire was one of the most destructive in the war annals of the U. S. Navy. Study and analysis of the fire aboard *Erie*, as well as of fires on other warships early in the war, resulted in many improvements in firefighting equipment and technique.



U. S. S. "ERIE" (P.G.50).

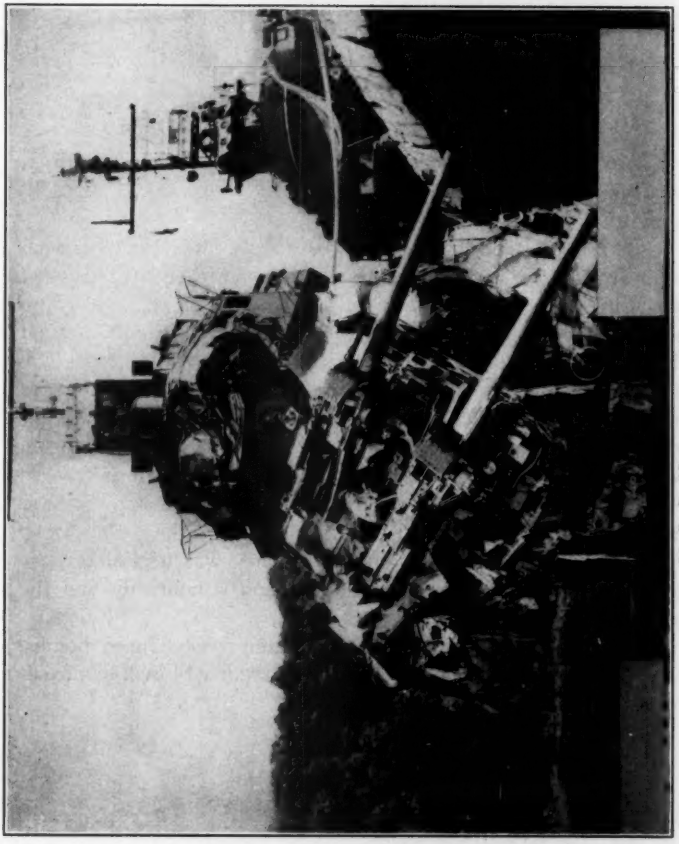
Photo 4: The U.S.S. *Selfridge* (DD357) at Purvis Bay in October, 1943. A unit of a U. S. destroyer force, she was struck by at least one torpedo, and probably two, during a night surface engagement on 6 October, 1943.

One struck at frame 40 starboard and the other probably at frame 30 port. The resulting explosion(s) severed the bow in way of No. 2 twin mount. The severed section floated aft along the starboard side, damaging the starboard propeller, after strut and tail shaft. As will be seen in the photo, No. 2 twin mount was demolished. Flooding aft of the break was of minor proportions, trim changing by only 4 feet. There was no fire.

Despite the loss of 100 feet of her bow, *Selfridge* returned to Purvis Bay at about ten knots. Both engines were used in spite of damage to the starboard propeller, strut and tail shaft (there was considerable misalignment) which caused some vibration.

At Purvis Bay wreckage was cleared away and the upper half of a temporary stub bow installed. She then proceeded to Noumea for drydocking, completion of the bow and machinery repairs. She crossed the Pacific under her own power to Navy Yard, Mare Island, where permanent repairs were accomplished.

Selfridge, one of the first class of U. S. destroyer leaders of 1850 tons standard displacement, proved to be typical of the ruggedness of U. S. destroyers, many of which survived damage of similar proportions.



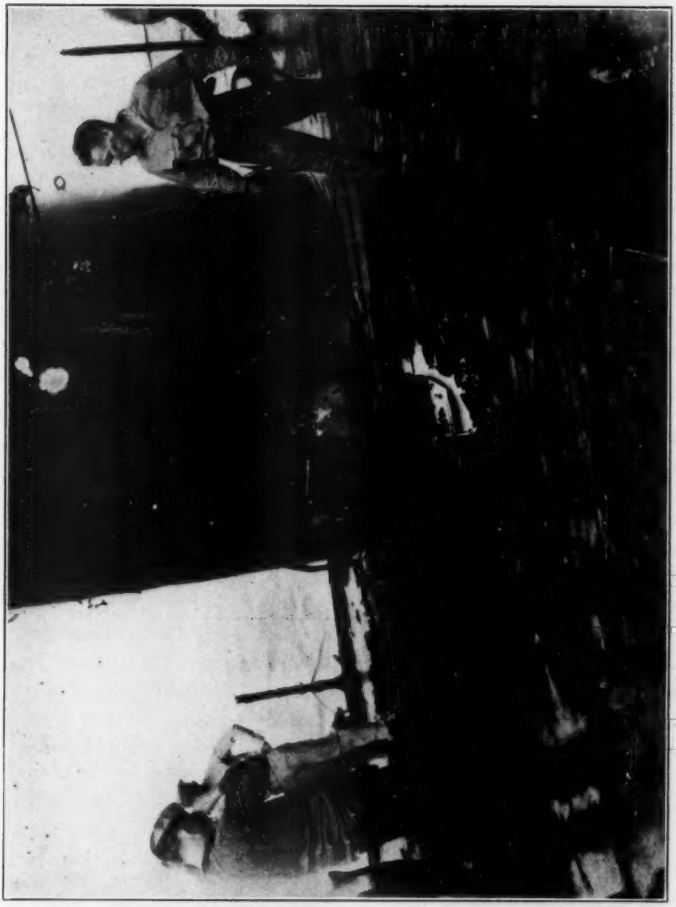
U. S. S. "SELFRIDGE" (DD357).

Photo 5: Damage to the U.S.S. *Chester* (CA27) caused by a small bomb on 1 February, 1942. The photo was taken about 40 minutes after the hit.

Chester was struck while a unit of a U. S. task force engaged in the Navy's first offensive action of the war—the strike against the Marshall and Gilbert Islands. The formation was undergoing a dive-bombing attack when *Chester* was hit by a small bomb on the main deck just inboard of the port catapault foundation. The bomb obviously detonated upon impact with the deck. Intelligence information indicates that the bomb probably was of the 60 kilogram, general-purpose type. Fragmentation was excellent, causing several casualties and much minor damage in the form of severed electrical cables and punctured ventilation ducts and piping. Two minor fires occurred which were quickly extinguished.

The effect on *Chester's* fighting efficiency was negligible—one 5 inch gun was placed out of commission temporarily and the port catapault was deranged.

This damage, typical of small instantaneously fuzed bombs, should be compared with that in photo 6 from a 14 inch bombardment projectile.



U. S. S. "CHESTER" (CA27).

Photo 6: The damage to the U.S.S. *South Dakota* (BB57) caused by a 14 inch bombardment projectile. On the night of 14-15 November, 1942, *South Dakota* was a unit of a U. S. task force which engaged a heavy Japanese force in a gunfire action. In the ensuing engagement *South Dakota* received approximately 50 hits with projectiles of various calibers. The Japanese, enroute to a shore bombardment rendezvous, used bombardment projectiles against the U. S. warships. Such projectiles have little penetrative ability and usually are fuzed for impact detonation.

The projectile which caused the damage shown in the photo was of 14 inch caliber fired from a Japanese battleship. The projectile struck the barbette for No. 3 turret just below the shelf, detonating upon impact. The barbette and turret machinery within were undamaged. As shown, a sizeable hole was blown in the main deck. The majority of fragments were deflected down into the second deck compartment below. In general, fragments did surprisingly little damage.

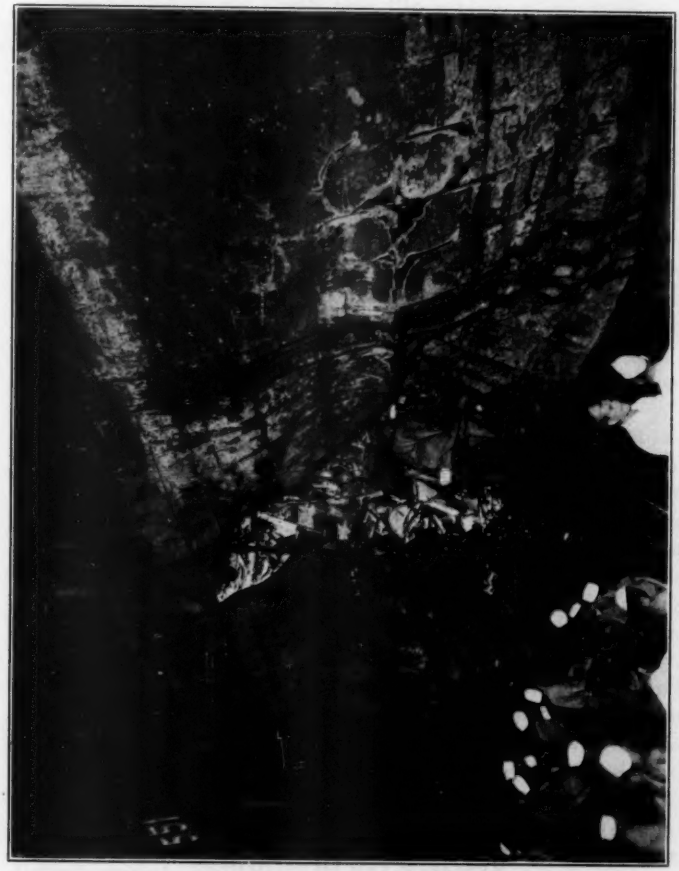
Damage from this large projectile was somewhat less than that caused by the small bomb which struck *Chester* (see photo 5). Nonetheless, it is typical of the damage caused by heavy projectiles against unprotected structures. Projectiles, even if high-capacity, have a small charge-weight ratio compared with bombs.

U. S. S. "South Dakota" (BB57).

Photo 7. The U.S.S. *David W. Taylor* (DD551) in drydock at Saipan about 9 January, 1945. She struck a mine during a bombardment of the island of Chichi Jima on 5 January, 1945. The point of impact was slightly above the keel on the port side approximately 50 feet aft of the stem. The photo shows the damage to the port shell in way of the point of impact. It is believed that the mine was one of the comparatively small moored contact type frequently employed by the Japanese.

Damage was serious but not extensive. Flooding caused an 8½ foot trim by the bow which later was reduced considerably by damage control efforts. She retired to Saipan at 17 knots where she was placed in drydock and temporary repairs accomplished. She then returned to the U. S. Naval Drydocks, Hunters Point, for permanent repairs.

The damage shown is typical of that caused to hulls of light warships by contact mines containing moderate charges of explosive.



U. S. S. "DAVID W. TAYLOR" (DD551).

SPEAKERS

ANNUAL BANQUET

5 April 1946

"SUBMARINE COMBAT EXPERIENCES IN THE PACIFIC"

BY

VICE ADMIRAL CHARLES A. LOCKWOOD, U. S. NAVY
FORMER COMMANDER SUBMARINES PACIFIC

"RESEARCH, ORGANIZATION, AND NATIONAL SECURITY"

BY

DOCTOR VANNEVAR BUSH,
PRESIDENT CARNEGIE INSTITUTION
OF WASHINGTON

AND

DIRECTOR, OFFICE OF SCIENTIFIC
RESEARCH AND DEVELOPMENT

SUBMARINE COMBAT EXPERIENCES IN THE PACIFIC.

By Vice Admiral Charles A. Lockwood, U. S. Navy.

Mr. Toastmaster and Gentlemen:

I feel much honored and not a little abashed to address a Society whose roster includes the names of so many illustrious engineers and noted men of science. Fortunately, however, I do not have to address you on engineering or scientific subjects. It is my pleasure and privilege instead, to give you a few illustrations of how the lads fighting the war in submarines employed the weapons and equipment which you sent them, and how they achieved the tremendous results which the world now knows they did achieve in World War II.

On this occasion I come before you in the role of a satisfied customer, an enthusiastic endorser of your products.

Of course we did get a criticism about George Codrington's engines. One night I received an urgent despatch from a submarine skipper off the China Coast who was trying to escape on the surface from Jap escort vessels. He had made an attack close inshore on a convoy and was using every last ounce of horsepower to leg it for water deep enough to dive in. He told me of his predicament, which looked pretty desperate, and closed with the despairing words—"Four Wintons cannot outrun four destroyers." However, I am happy to say that he did get home safely. George showed me a new engine he has built out in Cleveland which he guarantees to outrun any number of destroyers. I also had reason to believe, while in Cleveland, that George is experimenting with atomic power, for certainly some of the liquids he fed me there packed a tremendous wallop. Better men than I, so I am told, have also barely survived his Navy Day celebrations.

At the beginning of the war, we did, as you know, have bitter disappointments with the exploders and depth keeping of our torpedoes. Captain Roy Benson, then commanding the *Trigger*, had a heartbreaking experience which was typical of many others. The *Trigger* was patrolling submerged about twenty-five miles south of Tokyo Bay entrance late one evening in June 1943 when

he sighted the Jap carrier *Hitaka* with two DD's and some air cover standing out. The situation developed beautifully and the *Trigger* bored in to an ideal position 1200 yards on the target's starboard bow. From this position he fired six torpedoes and obtained four explosions. The first two he saw, apparently forward of amidships, but he says that no debris went up with the tremendous plumes of water. The next two which should have been further aft along the target's length he didn't see because a DD was right on top of him and it was necessary to get down deep and quickly. There the DD's kept him for about seven hours, working him over with periliously close salvoes of depth charges. During that time, as we now know, the Japs took the *Hitaka* in tow and finally got her back to Yokosuka with a draft said to have been 51 feet aft and very little forward. Hence the first two explosions must have been prematures, and the other two explosions were hits aft. If she had been 100 miles further from port the *Hitaka* might have sunk before she could be docked but, as it was, those first two prematures undoubtedly robbed us of a much needed kill.

Finally we inactivated the magnetic feature of the exploder but, alas, that was not the end of our troubles, for immediately we encountered a serious percentage of duds with the straight contact exploder.

I won't bore you with details of how we cured this trouble, but I want to give full credit to a lot of smart lads out in Pearl Harbor including "Swede" Momsen, Tom Eddy, "Penny" Pendleton, Art Taylor, "Pie" Pieczentkowski, George Hodgkiss, and Commander Ellis A. Johnson of CinCPac's staff, (who in civil life is a mathematical physicist at the Carnegie Institution of Washington). The way they tore into the problem and, in less than a month, solved it right there in the machine shops of the old *Holland* and of the Submarine Base, was a splendid example of what can be done when you get a lot of people to wholeheartedly pool their brain power and concentrate on a particular problem.

The results far exceeded our expectations; the morale of our skippers went up by leaps and bounds; and the next three months, the months of October, November and December, 1943, showed sinking records which were surpassed by only a few monthly sinking records for the entire war.

On top of this important success came other successes—our

engines were running like sewing machines, the Bureau of Ordnance built us a new torpedo exploder, the new electric torpedoes from the Westinghouse Plant at Sharon were being delivered to us—and by us to Tojo; false target shells were helping our subs to evade; radar was beginning to make night attacks one of our major sports; and new submarines were arriving in sufficient numbers to permit us to engage in a long desired enterprise, that of sending wolf packs into the most productive areas around the Marianas, the East China Sea and in Luzon Strait.

These gains, while most encouraging, were not without their accompanying losses, for in the months of October and November we lost six submarines in Asiatic waters and one in the Caribbean. Among these was the *Wahoo*, lost probably in the Sea of Japan, commanded by Comdr. "Mush" Morton of whose outstanding ability and aggressiveness no doubt you have all heard. He was the first to destroy an entire convoy single handed and he it was who entered Wewak Harbor in north east New Guinea and blew the bow off of a Jap DD while it was attaking him.

The *Sculpin* was also lost at this time under very tragic circumstances, as we learned after the war. She attacked a convoy north east of Truk on 19 November 1943, just the day before the Marines began the bloody battle of Tarawa. *Sculpin* was part of the covering force for this operation and the wolf pack leader embarked in her, Captain John Cromwell, of necessity had been given an outline of the general plan of the operation. The attack on the convoy failed and during the ensuing depth charge counter-attacks which lasted about five hours, a particularly close string of 18 charges threw *Sculpin* out of control and she went down deep. The hull was distorted, outboard valves were leaking badly, the torpedo tube doors were jammed and so much water had been taken into the hull that high speed was required to maintain depth control. Use of high speed of course made tracking an easy matter for the DD. Added to these troubles was the fact that the battery was almost exhausted and the depth was too great to permit lying on bottom.

After some discussion as to the best course to pursue, the commanding officer, Commander Fred Connaway, decided to surface and fight it out with his 3-inch gun, two 20 mm's and what 50 calibers they could rig. It was a last desperate chance, as he must have known, and the ensuing engagement with the DD *Yokahoma* soon reduced the topsides and C.T. to shambles.

After Comdr. Connaway, Lieut. Allen and Lieut. Defrees, with most of the men on deck had been killed, Lieut. Brown, the senior ship's officer remaining, ordered the ship scuttled.

Captain John Cromwell, when informed that the ship was being abandoned, said, "I can't go with you, I know too much," and was last seen seated in the Control Room. Ensign Fiedler also preferred death to capture and is said to have been last seen in the wardroom playing solitaire.

And so the old *Sculpin*, whom you may remember as having been the ship which located the *Squalus* when she sank off Portsmouth in 1938, went down with colors flying and engines running. The lads in the water say her last dive was as pretty as any she had ever made.

The Japs picked up 42 prisoners, threw one overboard who was wounded, tried to throw over another who was vomiting from having swallowed too much salt water and took the remainder to Truk.

The sequel to this story was written two weeks later just before midnight on 3 December when the *Sailfish*, which was originally the *Squalus*, picked up four radar pips, two large and two small, on a northwesterly course while patrolling about 300 miles southeast of Tokyo Bay.

The weather was of typhoon caliber, 40-50 knots of wind with mountainous seas, a driving rain, and very low visibility. Lieutenant Commander Bob Ward, the skipper of the *Sailfish*, however, considered this all in his favor in spite of the chance of poor torpedo performance in heavy seas. His new radar had recently been installed, his crew had been trained in the technique of radar attacks at 42 feet and he was eager to try out this new equipment.

Difficulty was encountered in reaching attack position because he could not work up to better than 12 knots against the heavy seas. However, just after midnight he reached a position on the port bow of one of the larger pips with a DD 400 yards from him and signalling with a searchlight in his direction probably demanding a recognition signal. He thereupon carried out beautifully the procedure for radar attack by submerging to 40 feet where his radar antennae was just out of water, and fired entirely on radar range and bearing. From his first four shots he got two hits on the still unseen target and then went deep to avoid the expected pounding with depth charges. However, the DD's were

probably having their troubles in locating him in the heavy seas, added to which was Ward's smart maneuver in crossing close astern of the target. Hence at 0200 he was able to surface and found his target to be circling. She finally steadied on a course at about four knots whereupon he again bored in, this time on surface, fired three bow tubes, and observed two hits.

The Nips then started a Fourth of July celebration and since daylight was approaching and tracers beginning to come his way, Ward submerged and reloaded preparatory to another attack, convinced that his target was now a dead duck.

At about 0745 *Sailfish* stood in submerged and at last was able to see her victim—a carrier, dead in the water, with a DD dashing madly about. She was badly listed and her flight deck was covered with personnel and planes which, from time to time, slid over the side. Ward made an inspection of her and sketched her profile in order to make sure of her identity. Then he let her have three more torpedoes, two of which hit and finished her career.

This battle, which took from midnight until 9:40 in the morning, was fought with a skill and determination seldom surpassed during the war and it scratched one flat-top at a most opportune time.

Not till the end of the war did we learn to our sorrow, that this flat-top, the *Chuyo*, had on board 21 prisoners from the *Sculpin*, 20 of whom went down with her.

No story of material sturdiness and personnel guts is complete without the story of the *Tunney*, Commander John Scott, who in August 1943 intercepted an unlucky six charge pattern dropped by a trawler off the entrance to Babelthuap Harbor in the Palau Islands. Two charges exploded over the Maneuvering Room knocking out all power, the next pair exploded alongside the Conning Tower and, as John Scott expressed it, the conning tower left the hull, but just by coincidence came back in the same place. The third pair were just under and on either side of the bow so close that the exploder from one and many pieces of the casings were found in the superstructure after surfacing that night. The bow was so twisted and dented that it was necessary, when she limped into Mare Island, to remove the torpedo tubes, rebore and re-align them and to renew all hull plating back to the torpedo room hatch. Innumerable other casualties had occurred, but as I have said, she got home with head bloody but unbowed.

Next spring when she came back to us at Pearl, I asked John Scott what patrol area he'd like to have. He said, "Palau: I've got a little unfinished business down there."

He arrived off Palau just before our first big carrier strike scheduled for 1 April 1944 and, while waiting for the expected run out of Jap ships, he sank one heavily loaded AK, one DD and one I class submarine. In preparation for the strike, we had placed six submarines in a semi-circle along the west side of Babelthuap Island and *Tunney* had a ringside seat. Somehow the Japs got advance notice of our impending strike and the rush began. Ships, mostly small stuff, came pouring out of the harbor, but John had seen men-of-war at anchor in there and he decided to wait for bigger game. His reward came when, late in the evening, a BB, a CL and three DD's were sighted standing out. Unfortunately his estimate of the speed of the big BB, later known to be the brand new *Musashi*, must have been too high, or perhaps she managed to take evasive action for only Nos. 4 and 5 torpedoes out of a spread of six, hit, and both those were forward.

We can rest assured, nevertheless, that the *Musashi* spent some time in the yard after receiving those packets, and I rather figured that John Scott and the *Tunney*, with the bag they got, had taken their revenge for their former beating.

But somehow Palau was unhealthy for *Tunney*, and next morning, while lifeguarding on surface, one of our own planes dropped a 2000 pound bomb alongside her engine room and again she went limping to the nearest base for repairs.

The most remarkable example of our success in sinking enemy submarines and of the value of the APR gear which you sent us, was provided by the *Batfish* commanded by Commander J. K. Fyfe. She was on station north of Luzon at the time when General MacArthur was squeezing the Japs northward. With their sea and air communications cut off, we rightly expected night reinforcement or evacuation activity similar to those which were attempted at Guadalcanal and Leyte. We, therefore, put three submarines in position to counter any such moves. The *Batfish* was nearest Luzon and on the normal traffic route between Luzon and Takao in Formosa. Sure enough, her first night on station she picked up on her APR indications of an enemy radar north bound which she followed until eventually

she sighted a dark shape through the gloom quickly identified as a Jap submarine. I may say at this point, that the silhouette of our submarines differs greatly from those of the Japs and of the Germans. Therefore, we are able to identify our own submarines very readily. Commander Fyfe approached this target to 1850 yards and fired four torpedoes, all of which missed. These torpedoes exploded at the end of their runs, some distance to westward of the Jap, but he evidently paid no attention and buzzed merrily along. Commander Fyfe immediately hauled out to 5000 yards and, by putting on speed, gained a position ahead again. The night was very dark, no moon, partially overcast, and so this time he decided to come in much closer, and closed to 900 yards without the target giving any indication that it was aware of his presence. The *Batfish* then fired three torpedoes, one of which struck the Jap, who sank immediately to accompaniment of loud breaking noises. She closed the spot and turned on her searchlight in an attempt to pick up a prisoner or two in order to learn the identity of the victim, however nothing could be seen except a heavy oil slick with the very distinctive smell of Diesel oil.

The following night and again the night after that *Batfish* picked up the now familiar enemy radar on her APR search receiver. In each case Commander Fyfe was able to home on the Jap radar and in each case he got into close range and sank his opponent.

It is interesting to note that in both of these last cases the Jap sub made what was evidently a routine training dive during Fyfe's approach. However, he tracked along on the probable course of his enemy and once, so good was his sonar gear that his sound man reported, "Captain, I can hear someone blowing ballast tanks." Immediately thereafter the Jap search radar indication reappeared on his screen and he knew the enemy sub had surfaced.

Thus in the space of 76 hours, *Batfish* with the aid of APR search receiver and some very smart headwork, bagged three enemy subs and undoubtedly a goodly amount of much needed supplies for Yamashita's army.

Instances of the expert use of radar and of determined and annihilating attacks against enemy merchant convoys by single submarines and by wolf packs are too numerous to be told here, so I shall confine myself to some of the lesser known sinkings

which had important strategic or tactical value and which are replete with "blood and guts" as requested by our genial chairman, Admiral Roger Paine.

Two sinkings of utmost importance were accomplished by *Cavalla*, Lt. Comdr. Herman Kossler, and *Albacore*, Lt. Comdr. Jim Blanchard, on 19 June 1944, just before the First Battle of the Philippine Sea, when they eliminated two big CV's, the *Shokaku* and *Taiho* in the area southwest of the Marianas. The first one was hit by three torpedoes but the *Taiho* was hit by only one torpedo, which struck under her forward elevator and ruptured her gasoline tanks. The liberated gasoline rose into her hangar decks and desperate attempts by the Japs to ventilate only succeeded in spreading the fumes throughout the ship. Six hours later she blew up with a tremendous explosion and the hulk was torpedoed by her own escorts.

In both cases the submarines were worked over for many hours by the Jap destroyers, so did not know till the end of the war what havoc they had wrought and what important aid they had rendered to Admiral Spruance's 5th Fleet in the climactic struggle then raging on Saipan. Most of the *Albacore's* crew never knew, as she was lost on her next patrol.

Two other valuable carrier sinkings were achieved by the *Archerfish*, Lt. Comdr. Joe Enright, and the *Redfish*, Comdr. Sandy McGregor.

The *Archerfish* encountered the *Shinano*, converted from a battleship hull, rated at 69,000 tons, on her trial trips south of Tokyo Bay. She passed *Archerfish*, well out of range accompanied by four DD's. Her speed was too great for the submarine to catch her as she passed about 3:30 in the morning of 29 November 1944, however Enright trailed hopefully and finally, as if in answer to his prayers, *Shinano* reversed course and he found himself, to his amazement, 10 degrees on her starboard bow. Events followed swiftly, culminating in the firing of six torpedoes with four hits and the final plunge to Davy Jones' Locker at about 1000. This last happy event, however, we did not know until afterwards due to long continued depth charging by the Jap DD's.

Redfish was both luckier and more unlucky than the *Archerfish*. She, at the end of a patrol cursed with misses, managed to get one hit out of four shots, fired from her forward tubes into *Unryu*, headed south, loaded with planes in East China Sea in the late

afternoon of 19 December 1944, when the Japs in Luzon with the Leyte campaign still on their hands, were in desperate need of planes. The torpedo struck aft and stopped the *Unryu* in her tracks. Instantly the starboard screening DD charged down on the sub from a range of 1700 yards. McGregor let the DD have four torpedoes from the stern tubes which, while they missed, caused her to turn away and increase speed, thus allowing *Redfish* time to observe the main target listing to starboard and burning aft.

This was not good enough for Sandy McGregor and he spent the next ten minutes screaming for the after room to load his last three torpedoes in order to give the coup de grace. Meanwhile, the CV was wildly firing all starboard guns and the DD's were milling around dropping depth charges indiscriminately. Finally one torpedo was loaded aft and from a range of 1100 yards he let the CV have it just abaft the island. Tremendous explosions followed and she began to capsize, but even then Sandy didn't try to escape; instead he took periscope pictures of the doomed vessel and set up his TDC for shots at the nearest DD.

Unfortunately, at this point, the DD evidently sighted his scope and charged down "looking like she was all bow wave." Sandy rang up full speed and headed for 200 feet, which is about all the water to he found in the East China Sea. At 150 feet, to quote the skipper, "All hell broke loose as a salvo of seven well placed depth charges exploded alongside the starboard bow." They seemed to shove the ship down and bodily to port and she wound up on bottom at 232 feet with dozens of material casualties such as a crack in the forward torpedo room hull plating, 12 broken battery jars, bow and stern plane gear out of commission, gyro compass 50 degrees off its proper heading, and one man's ear nearly severed by a watertight door which escaped from its fastenings. To make their misery even more complete, one of their two remaining torpedoes was running hot in a stern tube.

But did the McGregor or any of his troops crack under this treatment? Not those boys! After two hours more punishment he surfaced that night and headed for home, badly battered but still in the ring.

On Christmas day while nearing Midway, he entered in the patrol log: "All hands enjoyed a delicious Christmas dinner and

have now begun to breathe easier; it's been pretty tough going since the attack on that carrier."

His final entry says: "All hands wish to offer their sincere thanks to the men who designed and built this sturdy carft."

And to that sentiment I and all submariners say a hearty "Amen."

Not only do we pay tribute to the designers and builders but to the clever lads in the Bureaus and manufacturing plants of the country who produced splendid equipment, gear and weapons, and also to the devoted scientists who rushed to our aid with almost incredible ideas which, when translated into equipment and weapons, saved hundreds of our lives and sank hundreds of thousands of enemy tonnage.

Yes, many a submariner who is alive today, owes his life to the reliability of your engines, to the stoutness of your hulls, to the accuracy of your torpedoes and to the wizardry of your electronic gear.

And many a lad who went ashore in the landing craft, many an aviator attacking the Japanese homeland, many a surface craft, owe their lives to the fact that, due to the submarines you produced, Japanese troops, munitions and aviation gas did not reach their intended destinations.

I wish to pay personal tribute to my predecessors and brothers in command of Forces—to Admiral Withers, Bob English—God rest his soul—Freeland Daubin, Babe Brown, Christy, Jimmy Fife and Gyn Styer—they have been towers of strength in our submarine world.

But first, last, and always I want to pay tribute to our squadron commanders, division commanders, commanding officers and crews of submarines. To their daring, initiative, determination, and just sheer guts, we owe the brilliant performance of the boats you built and the success of the submarine part of the greatest naval war that has ever been fought.

RESEARCH, ORGANIZATION, AND NATIONAL SECURITY.

By Dr. Vannevar Bush.

The subject I am to talk about tonight holds true of colleges, industries, military affairs, what have you. It is the fact that in any undertaking requiring joint efforts by large numbers of people, there must be a basic organizational set-up so planned that responsibility and authority are clearly defined and when responsibility is assigned, there is assigned with it enough authority to see that it is met. I welcome the opportunity to discuss with you certain applications of this principle, for the general subject has always been fascinating to me, and the special bearing of it in our present military situation has particularly important connotations.

The working solution of the problem or organization in any undertaking at a given time—the present structure of rank and of bureau organization in the Navy, for example—is a compromise between two opposed concepts. On the one hand, the urge to fix or "freeze" a presently efficient pattern is very strong. On the other hand, there is constant need for ready adaptability to altered conditions, for no organization operates in a vacuum.

This second concept doesn't apply too strongly in a great many activities. For instance, an iron foundry, an air transport service, a widespread farmers' co-operative society, can set up an organizational structure and be fairly sure that no major changes are likely in its operating conditions. But it is different with military affairs, with naval affairs. We need but review the past six years to be sure that the evolution of new weapons during a war may determine not only the outcome of battles, but even the total strategy of war. This had always been true to some extent, but the rate of evolution of military weapons during the recent war became more rapid than it had ever been before in human history, and it bids fair to go on increasing.

Adaptability—and that means quick and effective adaptability—to new weapons, therefore, is a quality which we must demand in the organization of our Armed Forces. We must

demand it both because it is essential to the security of the United States as a nation, and because we must have the United States the strongest of nations during the critical years while the traditional system of sovereign states is reaching solution of the strange new problem of building up the world teamwork that is imperative in controlling new techniques and new sources of energy. Military strength is a central factor in keeping the United States generally strong as a leader in this undertaking, and as I see it, the central factor in the military strength of the United States is bound up in this question of new weapons and the adaptability of our military organization to deal with them.

This question undoubtedly has an influence in the thinking of those who have been giving consideration to the various proposals for general reorganization of our entire military establishment, which range all the way from modest overhaulings within the existing Departments to the sweeping move of unification of the Services in a single Department of National Defense. As matters stand now, I favor the proposal for unification, because none of the other plans equals it in assuring unity in the areas where modern war demands it. Of these areas, the most important is that of adaptability to new weapons.

The new weapons which changed the pace of the past war and those which can be expected to exert the same influence on the next war, if one should unfortunately break on the world, are the products of research—fundamental research first and military research thereafter. The basic provision which we can and must make is to assure for ourselves the technological superiority which is the key to victory. We have during the war come some distance toward that goal, as compared to the sad situation which existed in this country between the two world wars, as far as military research was concerned. We must keep every gain that has been made, but by no means stop there. I decidedly do not mean by this statement, however, that we should extend our wartime organization into the peace. Such an argument is deceptive for two reasons—first, the fact that no temporary expedient, regardless of its temporary effectiveness, should be maintained intact after the passing of the emergency pressures which gave it being and vitality; second, the fact that no temporary improvisation, excellent as it may be, can be completely effective if the fundamental organization on which it is superimposed is either weak or unsound.

I do mean that those phases of military organization which are concerned with research must be so calculated as to preserve such lasting values as were gained from the improvisations of this war, in spite of the various difficulties which those improvisations encountered. The immediate form of the improvisation does not matter so much. The New Developments Division in the Army, for example, may be revised, but the attitude toward science and technology which, as far as conditions allowed, was embodied in it must not be displaced. Rather, the disabilities which hampered that attitude should be eliminated, and the attitude itself fortified and given additional emphasis. The same comment applies with the same force to various organizational steps in the Navy. There was and is a genuine effort to link research with the high command. It has not been completely successful. The important fact is that the effort has been made, and represents an advance on which to build in future. So also, indeed, with the Office of Scientific Research and Development on the civilian side of things. This goes out of existence shortly, but will be replaced, if Congress acts, by a permanent National Science Foundation. We had too, and still have for that matter, although on an imperfect foundation, a research and development body under the Joint Chiefs of Staff, which strived with inadequate authority to correlate interservice effort. All this organizational structure will undoubtedly change, and should for that matter, but the important point is that scientific research on military problems must be an undertaking of major stature, integrated thoroughly with all related phases of military affairs, and above all linked in with the upper echelons—brought into play at the top levels of planning and control. We did not through the various expedients of the past war achieve this ideal of top-level integration, not by any means. But we did make some progress toward it, and as we look to the future we must make full use of that fact, for in the future we shall not be able to defend this country properly or to keep it as strong as its international responsibilities require, unless we go all the way toward that ideal.

I have no hesitation about making that last statement a flat and categorical one, because as we all know the scientific developments which hastened the end of the last war were unprecedentedly powerful and have posed for the world problems without parallel. They promise that the next war, if, counter to all our hopes, there should be another war, will involve scientific and

technological enterprise to a degree never before experienced. This means that no matter how able and effective our combination of military and scientific thinking may have been in recent years, it has got to be even better in the years to come. The system by which we draw for military purposes upon the general store of basic research cannot have any rough spots; it must be efficient, smooth in operation, swift in execution.

There is plenty of reason for confidence that we shall have a rich store of general research on which to draw. Broad support of research by the Federal Government, as provided in legislation now before the Congress, is an assurance of this. Moreover, it is an assurance that much needed action will be taken to overcome the shocking deficit of able young scientists which was caused by our shortsighted use of manpower during the war and which I know has been a regrettable hindrance to some of you gentlemen in carrying out your present plans.

Now when we speak of drawing on this fund of general research for military research, we run into certain difficulties, for we cannot now decide what is military research and what is not military research in terms of a war a generation hence, for we cannot discern what the nature of such a war might be. We do know, however, that military research is applied research—that when a unit of basic knowledge ascertained through fundamental research is seen to have probable military utility and when men go to work to bring that probable utility into reality and application—it is essential that the objective be clearly stated, and that the work be at all times clearly tied to it. The task of the man responsible for the proper direction of research for the Army and the Navy therefore is a double one. They must be sure that their units are always in close touch with the basic research going on here, there and everywhere in a great scientific and industrial nation, and are always alert to single out of the great mass the individual facts and findings which have promise for military purposes. They must be sure, also, that once this has been done, energies are properly focused, and kept properly focused, on the job of swiftly and effectively making the transformation of an abstract idea into a tangible weapon or instrument. For the first part of the task, dependable and thorough liaison with research agencies throughout the country is vital. For the second, breadth of vision and firm, reasoned control are essential. Such liaison and such control will be secured only as a difficult

task of organization, correlation, co-ordination is successfully accomplished.

Though our over-all postwar military framework has not as yet been defined by Congress, and though as a result we cannot explicitly discuss the detailed problem of organization for military research and development, certain cardinal principles are clear. To these we can turn attention. First among them is one which I have already stated: There must be adequate planning at the top both for the evolution of weapons and for the strategic use of new weapons. It is not enough for us to plan the defense of this nation in terms of existing or even immediately foreseeable weapons; but there is a strong temptation to plan this way, in view of all the complexities of logistics, training, intelligence, and personnel. The planning for immediate campaigns must of course be done in just this manner. But the long-range planning of a whole war—and particularly of a war to be forseen at some unpredictable time in the future—must be done in terms of the evolution of weapons and strategy. It has been the custom for advanced military thinking on the technical aspect of this matter to be left to the lower echelons, on the theory that if an idea was good enough, it would force its way to the top and demand due attention. In earlier times, maybe this was all right. In our time, it is not. Progress in complex technical matters is slow enough, what with inertia, limited vision, obstinacy, vested position, and all the other ills that flesh is heir to, without superimposing the organizational handicap of making new thinking fight its way to the attention of the top-level commanders who ought to be giving it affirmative consideration.

Both the secure affirmative direction and drive for new developments and their use, and to make sure of proper co-ordination of the work of the several Services or of the work of the several divisions within one Service, our postwar system must in the scientific field embody the sound principle of military organization which it now does not—the principle that responsibility must be definitely assigned and that responsibility and authority must go together. During the war, the Navy and its companion branches in the national military establishment, by means of expedients which I have mentioned and of others with which we are familiar, secured a workable emergency solution for this trouble. In the years to come, we must do better, we must so arrange matters that responsibility and authority for saying

"yes" and "no" will be regularly provided at every level where they are needed. The standard answer, that the President as Chief Executive holds this authority and this responsibility is true enough, but it is only common sense to realize that in the majority of cases they must be exercised for him by properly chosen subordinates responsible in clearly defined areas to his principal aides, such as the Secretaries of War and Navy. Moreover, most of the differences with which we are concerned tonight arise in areas where special skill and knowledge are involved, and must be settled by those qualified through special training. Modern war, particularly, with all that it means of overlapping and joint interest in the extended interrelationships of land, sea, and air, brings about more of these specialized divergences than any other activity of mankind. With this increased interrelation must come corresponding organization.

Specifically, in a pyramidal organization of our Armed Forces, which splits immediately at the level of the Secretaries, there must be provision for the resolution of the manifold overlapping interests of land, sea, and air at the level at which they occur, positively and authoritatively, and without expecting every dispute to work its way up to the top echelon or remain unresolved. This problem remains whether we have a single department or three.

The second cardinal principle, if recognized and effectuated, will go a long way toward resolving this trouble. This second principle is that the position of the technical man in uniform must be improved. By this I mean that men in responsible positions should have better training, and that soundly trained technical men should be eligible for high command. If that means junking the strange idea that a man who by hard work trains himself as a specialist at the same time disqualifies himself for high command, then let it be junked. Where this traditional limitation on the technically trained specialist came from is hard to understand. We are all familiar with its operation, however, as seen for instance in the oldtime Construction Corps of the Navy, which produced outstanding combat ships and during its history attracted many of the finest minds in the Navy, and yet did not furnish a corresponding quota of officers to positions of high command. The traditional argument, as I have been given to understand, is that the man who specializes in an advanced technique, say in engineering or science, cannot learn the sea

and the art of command in addition. There is in this argument an implication, too, that technical pre-eminence is incompatible with the toughmindedness and common sense that win battles. Another groundless notion which may contribute to the trouble is the idea that research unsuccessfully conducted should be regarded as a permanent blot on a military career. To my mind, all three of these notions are flatly wrong. A better grasp of science and technology in the upper levels of organization would soon put an end to them.

The position of technical men in the Armed Forces must be improved not only by broadening their avenue to high command and by increasing and improving the fundamental scientific training—as is happily indicated in recent training plans—but also by improving the status accorded research and technology itself. Research can no longer be, as it too often has been in the Services, held as incidental or subordinate to the work of branches whose primary interests and responsibilities are in other directions. The procurement divisions can no longer be in charge of practically all research. The two concepts are basically incompatible; new developments are upsetting to the standards and schedules which express the constant urge of the procurement group to regularize and standardize in order to carry out its primary function of producing a sufficient supply of standard weapons for combat use. Research, however, is the exploration of the unknown. It is speculative, uncertain. It cannot be standardized. It succeeds, moreover, in virtually direct proportion to its freedom from performance controls, production pressures, and traditional approaches.

Development is another matter. Certainly there is a point, in the long path from fundamental research to use, where procurement should take over. When a new device is being engineered for mass production, then certainly those who are to produce it should also have responsibility for finally whipping it into shape. But, in my opinion, they should not control it earlier, either in its gradual evolution or its evaluation. The metamorphosis of weapons is certainly important enough today to give their creation an organizational status completely equivalent to that provided for their purchase.

Implicit in what I have said so far is the third cardinal principle to which I would ask your attention—the need of a genuine scientific interlinkage between the Services. How this will be met

depends in large measure on action beyond our immediate purview; until the over-all postwar framework of the nation's military forces has been determined, the observer can do no more than urge that whatever the framework is, it will be unsatisfactory unless it assures stable and continuing provision for a unitary approach among land, sea, and air forces in matters of research, in the evolution of weapons, and in the perfection of strategy employing them. On this topic I have spoken at length elsewhere, and I shall hence say only that our present system of joint boards under the Joint Chiefs of Staff, though it was made after a fashion during the war because of the fact that men will agree under the stress of emergencies, is intrinsically ineffective because such boards have no one in a position of authority to resolve the differences which inevitably arise when sincere men are dealing conscientiously with important issues.

Closely allied with the third is the fourth principle—that our postwar military organization as regards research must provide for a real and definite partnership between civilian scientists and the military. It should be a source of pride to Americans to remember the teamwork of military men, industry, and science during the war. We must not relinquish one jot of the spirit and the method which we learned from that experience. We must build on them. We must, moreover, face up to the fact that although research on military problems and military weapons is largely a military matter, it is not entirely so. The fundamental research on which we draw for applied military research is done primarily by the trained professional scientist and engineer. In our applied research itself, the civilian scientist and engineer necessarily participate at many levels. It is a mistake to believe that since science has military importance scientific research should be run exclusively by military men. On the contrary, civilian science must be allowed to do the job which by specialized training it is equipped to do. Civilian science cannot make its true contribution if its efforts are subject to the complete direction of the military or if it has no independent funds. The real answer, of course, is a partnership between the military and civilian scientists. As we seek to establish this, we must keep clearly in mind the fact that a true and effective partnership can be had only if both are equals in a common endeavor.

One aspect of this partnership involves civilian scientists and engineers within the structure of the Navy Department itself.

Either such men should be entirely on an equal footing, socially, professionally, and in other ways, with their uniformed colleague of equal age and accomplishment, or else the Navy should not employ professional civilians for reserach and development activities of importance, but should rather rely upon contracts for this purpose. The first solution is, of course, the acceptable one, and there has been real progress in this direction. Partnership with civilian service also means more than merely supplying a civilian agency with proper funds; it means that individuals of equal abilities must meet as equals, regardless of uniforms and civilian clothes, that the personal give and take of the war years, when contribution to the task in hand was the only measure of a man, must be carried on in the peacetime years. The traditional *esprit de corps* of the Navy, with all that it means in intregity and self-respect, is the best of bases for this sort of co-operation. I think we see a good sign of it in the Navy's present practice of contracting for research and development under a system which preserves the initiative and resourcefulness of the contractors.

For nearly two generations, the American Society of Naval Engineers in pursuing the objects for which it was founded, has contributed notably to the fostering of fundamental knowledge and the bettering of professional practice in a field of vital significance to the well-being of the nation. As the Society resumes tonight this annual gathering deferred for five years by the demands of war, it has been a privilege to place before you these thoughts on a relationship which is of critical importance to our country. What I have said grows out of my convictions as an American citizen and as one who has been fortunate in the opportunity to share with military men, industry, and science in the great efforts of the years just past. Few men in our country are so well qualified as the members of this Society by professional training and by patriotic spirit to judge of the necessities which may confront us, or to meet them successfully as they form.

PRIZE ESSAY.*

"ENGINEERING IN THE NAVY AS SEEN BY AN ACTIVE RESERVE OFFICER."

By Donald L. Herr, Lieutenant Commander, S(E3), U.S.N.R.†

An old professor of mine, in giving his annual introductory lecture to new engineering freshmen, always used to say that "engineering is the practical solution of practical problems." That is indeed a broad definition. It seemed so to me then. But, after almost five years of active engineering duty in the Navy, I believe that the old professor, without actually intending so, gave a fairly adequate definition of engineering in the Navy as seen by an active Reserve officer.

What I write here can only be the recording of those impressions made upon myself. As such, they represent a synthesis of my own engineering background in industrial and academic research and development with those tasks assigned me in and by the Navy. It may be helpful, from the standpoint of perspective, to list these duties. Briefly, they comprise two and one-quarter years in a technical design section of the Bureau of Ships, with much temporary additional duty inside and outside the country and aboard ship; one and three-quarter years in the usual, and in some most unusual, duty in a new Navy Yard (Naval Drydocks, Terminal Island, California); a brief tour in the Navy's Engineering Experiment Station; and, finally, duty in the new Office of Research and Inventions. Somewhere in the chronological middle of all this, I was subjected to the usual two months' indoctrination course.

From the standpoint of establishing my own perspective more clearly, at this time it may be pertinent and helpful to others who read this article to mention two facts bearing on why and how I became a Reserve officer of the U. S. Navy on active duty. First, after listening to many of the broadcast speeches of the European

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* This paper received the Society's Prize Essay Award for 1945.

† Office of Research and Inventions, Navy Department, Washington, D. C.

demagogues in 1937 and 1938, and observing the shaping of things to come, I concluded that someday, perhaps soon, there would be increased need for technically trained men in the Naval organization. The result was that, at this time, I successfully applied for the Reserve commission of ensign. Second, just a year before Pearl Harbor, convinced now of the intensely technical aspect which the war had assumed and would continue to increasingly assume, I came on active duty as an ensign in the new Bureau of Ships. I came to assist in the original development and application of some of the new devices and technical weapons which were being thrust into the category of "imperatively necessary" by the technological warfare developments of the common enemy.

So much for motivation; so much for my belief that I would be of most direct use in the oncoming war effort in active engineering duty in the Navy. Although I attempted to anticipate, little did I realize the tremendous adjustment, change and growth that I was to undergo at the highly anonymous "hands" of the Navy.

Not the least part of my education in the Navy has been concerning (1) Naval organization and customs, (2) conference etiquette, (3) Navy correspondence forms, in general, and Bureau of Ships letter systems, in particular, (4) Navy financing, (5) shipboard traditions, (6) travel procedures, and (7) pay methods. All these items are merely mentioned in this passing paragraph as some of the extra-engineering details which had to be learned as rapidly and thoroughly as possible, to help get the basic engineering job done efficiently. Those of us to whom the Navy had not been a life-time career had much to absorb in one large "dose" both as regards Navy methods and Naval engineering. It is most interesting, and somewhat satisfying now, to view in retrospect just how useful these Naval procedures have been in helping to find "practical solutions to practical problems" in Naval engineering.

Engineering in the Navy, as I have seen it, *is* different. Because of the large number of sources from which engineering problems arise in the Navy—from the operating forces, the design agencies, the interdependent Bureaus, the industrial companies supplying the Navy, and finally, from the results of the tests imposed by actual battle—the accurate definition of the Naval engineering problem is generally a highly complex matter. Thus, even the

statement of the requirements is constantly changing, perhaps not always in fundamentals, but almost always in practical details. Yet, quantities of working equipments must be designed, procured and installed aboard ship in time for battle operation. That is the truly basic objective, to "get there the 'fustest' with the 'mostest' and the 'bestest'!" Between these extreme demands which are constantly being made upon the Naval engineer in a dynamic, rapidly moving technological war, lies the "practical solution."

This practical solution must be found directly in war-time. Sometimes, but most rarely, it can be devised by a single individual working at a desk. Sometimes it can find almost immediate embodiment as a plan on the drawing board or as a working instrument or equipment. Most commonly it requires large-scale cooperative effort between Naval officer and civilian personnel and the engineering and manufacturing representatives of industrial design and production agencies. On this front there occurs a close and continuing interchange of information and definition of technical needs, operational requirements and manufacturing possibilities. The resulting compromise is the practical solution.

Very often in this war, however, the practical problem requires for its solution the actual invention or adaptation of absolutely novel weapons, devices or equipments, or the utilization and extension of new fundamental physical principles. Specific instances are now too well-known and appreciated to require mention here. It is in this area, at the forefront of Naval technology, that the war-time requirements are most demanding and urgent.

The proper allocation of these research problems to Naval and other government or industrial laboratories and scientific agencies is a necessary and important step in finding the practical solution. This requires careful consideration and choice, based on full appreciation of the technical and priority problems involved, of the agency or agencies selected to carry on any particular program. It also requires active coordination and follow-up with all activities engaged in the research solution of the particular problem or related problems.

In the intermediate and final stages of achieving the solution, shipboard trials must be utilized quite frequently. Here, another type of coordination—with the operating forces—must be effected. In the field of Naval research and development engineering, the

embodiment of the ultimate practical solution may take unexpected form or impose new operating requirements upon the ship's force. This has occurred many times in World War II. The job is not complete until the resulting changes have been reduced to a minimum and those clearly defined for the steps which necessarily follow.

Those of us who personally have engaged in devising and engineering new weapons in this war are deeply impressed by the great multiplicity of technical problems connected therewith and the urgent need for their solution. Not the least of these has been the need to visualize at the outset, if possible, not only the detailed functioning of the new apparatus (once the basic principles of operation have been established) but also to visualize approximately the ultimate physical embodiment thereof. This is seldom possible at the beginning of the project, but the earlier in the course of the investigation that it can be done, the shorter becomes the path to the final production model. Here is the essentially unique demand made by Naval research and development engineering in wartime.

Once the practical solution is approved and accepted, final design, specification, procurement, manufacture and shipboard installation must be expedited with all speed. There are strategical, tactical, shipbuilding, conversion, material and personnel programs which are all being simultaneously synchronized and with which engineering changes, improvements and equipment installations must be synchronized. In modern war, to spare all lives possible and yet win militarily, the entire effort is a concerted action *en masse*. It is small wonder that some non-participants not directly nor actively engaged in the complicated business of Naval engineering have stopped to criticize or comment unfavorably upon a single aspect of some knotty Naval design, engineering or procurement problem or the manner in which its solution is being effected. Today, war in all its aspects, and especially in the technical and technological, is indeed involved.

So, Naval engineering does appear different to me, first of all, in its aspect of complexity on the technical side. This technical complexity is certainly augmented by the fact that the engineering of Naval equipment comprises at least two distinctly different phases. Let me make myself clear regarding these two phases.

The engineering and design of Naval equipment are only half-

done when a practical solution is found which "works" well in a laboratory, factory, or other place on shore. Adaptation or re-design of the entire equipment to meet, for example, the specific and extreme temperature, humidity, mechanical stress, shock, vibration, space, weight and fuel requirements of shipboard operation, requires almost always as much ingenuity and thoroughness as the technical functional design itself. The Naval engineering difficulties in meeting those requirements, are increased, I believe, by the lack of a sufficiently large and cohesive group of Naval design experts in the required fields to cope with the new technological problems of this war. Fortunately, this is not nearly so true now as it was in the hectic days of 1940-1943. This fact, coupled with the absolute need in that period for all of us to perform so many detailed non-engineering functions in addition to technical engineering presented a severe crisis which, fortunately, we have now largely passed—and successfully.

For example, I can remember the brief period of wonderment through which I passed in my first weeks of active duty. I wondered at having to prepare procurement requisitions, follow-through on production schedules, "worry about" material supplies for the contractor, progress the shipboard installations, and a whole host of other problems largely and normally the province of the material engineer or expediter. The point remains that the job had to be done. Those of us on the job engaged in the development of new devices had to share considerably in the "horse-work." At that time, and I suppose as always, this phase of engineering duty, while not as attractive nor as satisfying to the development engineer as the more creative engineering, was as vital as all others. Without the "carry-through" on production, without effective *use* in great quantity, all of the new types of weapons in the world would not avail nor help make possible striking the blow for victory.

In a second gross aspect, Naval engineering, as performed in this war, is different. It is different because of the tremendous influx of personnel—*while the war is being waged*—all such personnel having wide divergencies in background, experience and qualifications. The ultimate effect of this influx, I believe, is not only to provide sheer physical growth in the needed manpower, but also to instill a new vigor and fresh ideas and to germinate new spiritual and intellectual growth in the Naval organization

as a whole. Needless to say, along with the advantages accruing from the necessary numerical growth, the personnel administration problems occurring during such an influx are tremendous. It is surprising to me to see how smoothly, on the over-all, this growth and absorption have been effected.

Most of these new personnel, at least in Naval engineering, came to their new tasks without too many pre-conceptions of them. They came so rapidly and in such numbers (as had to be the case) that duplication of effort or mis-placement of abilities occurred in some cases. But, in general, there was more than enough engineering work of all types to go around. Some square pegs got into round holes, and vice-versa. The point remains that the job somehow had to get done, and was done. After a time, many of the good administrators of Naval engineering delegated much of their detailed duties and responsibilities to the new men, who normally in peace-time would not be "taking on" jobs of such magnitude for five or ten more years of their professional lives, if then. Most met the challenge. Most, indeed, seized at the opportunity to perform duties of such increased scope.

It seems to me that almost without exception, civilian and officer, regular and reserve, realized only too well that here in Naval engineering was a task requiring the utmost in team-work, cooperation and sharing of responsibility, and, above all, demanding unstinting endeavor by all to accomplish more with the passing of each day.

War-time engineering in the Navy proceeds under other conditions of stress. So many of the equipment requirements have been new that many existing engineering specifications could not be used. (Who can name a *single* Navy design which has not been changed or innovated during this war to meet present Naval requirements?) Very often, the contract description of the equipment served as the nucleus of a new basic specification. Many technical specifications could only be issued as brief interim specifications because of the rapidly changing development and design status and the marked changes in technology which were simultaneously occurring. Not the least of these changes in technology have been those dictated by the enforced use of substitute and synthetic materials and resulting new processes of manufacture. In such cases, the existing standard, peace-time engineering specifications could only serve as the starting-point for change.

If I were to summarize in a few words the job of Naval engineering in wartime as I see it, I should say that it is "to ensure that (1) the new Naval equipments and constructions in wartime are designed, completed and placed in operating condition ready for battle, (2) in two-thirds the scheduled time, (3) with a reserve production potential 150 per cent of scheduled requirements, and (4) with the new technical warfare requirements of new designs already on the drawing-board in preparation for the next stage." Naval engineering in total war is dynamic, complex and basically challenging to all our resources and stamina as well as to our technical skill and vision.

So far I have attempted to accurately record my own impressions of Naval engineering in this war, based upon those detailed experiences and incidents in which I have been either a participant or an onlooker. In the foregoing recital of these observations I have purposely refrained from criticism, constructive or otherwise, of Navy methods of engineering. There was not the place and then was not the time to inject personal opinion or belief. On the other hand, the foregoing effort to objectively relate my impressions of Naval engineering in wartime should not be interpreted as complete acceptance on my part as an individual of what is categorically known as "Navy methods", nor as an attempt by me to justify same. Indeed, "by their fruits ye shall know them." The over-all results speak for themselves, and will continue to do so, I believe.

However, I should regard myself as blind, indeed, and an abjectly unprogressive non-individual, were I not to also write down those deliberate constructive suggestions for consideration which are as definitely a part and result of my "seeing engineering in the Navy" as all that which has gone before.

The specific facts and general situations motivating the following suggestions for improvement are too commonly known to require repeating here. Hence, no novelty is claimed. The end-objective of listing these suggestions as the conclusions to this paper is to voluntarily add to that large body of first-hand data needed by those who are responsible for and intensely interested in shaping the future progress of the United States Navy, in general, and of its engineering phases, in particular. In this respect, I have considered this paper to comprise not only an entry in a prize-paper competition of high professional standing

but also a performance of that type of duty known in a line organization, such as the Navy or a large industrial corporation, as "staff work." As such, the following summary of suggestions is constructively offered in completion of my staff work in this article:

Summary of Suggestions for the Future.

1. Progress in all branches of Naval engineering in the post-war period must not be permitted to regress to that low level of activity characteristic, in general, of the "peace" years between the end of World War I and the beginning of World War II.

2. United States Naval engineering in the post-war period must remain abreast of, and preferably ahead of, all world-wide technical advance with respect to naval and military applications.

3. A large progressive staff of civilian professional experts in all branches of Naval engineering must be actively maintained by the Navy within the Naval establishment at all times. Continual additions thereto must be made from the best men in the oncoming classes of graduates from civilian engineering educational institutions.

4. Higher professional incentives, extra and distinctive rewards for merit, and active national publicity on all phases of Naval engineering must be provided and maintained in peace-time. The Congress and the people should be convinced that only with their full backing in appropriations, personal interest and lively curiosity regarding the Navy, in general, and Naval engineering, in particular, can possible future national tragedy be forestalled. For the Congress, the citizenry or anyone in the Navy to decry this statement is to have a short memory indeed. Let us not be blindly self-satisfied with our hard-won achievements in this World War II.

5. The curricula of the U. S. Naval Academy, especially in Naval engineering, must be kept abreast of the technical advances and modern engineering methods within and outside the Navy in peace-time as well as in war-time. If this means a little more engineering and science and a little less drilling and military duties let that be done. If it means several post-graduate years for all Academy graduates, let the base be expanded and double or triple the number of midshipmen going through the Academy at any one time. If it means fuller use of civilian educational and

scientific institutions, may the Navy make use of them on a general contract basis.

6. Close, effective liaison by the Navy with industrial, scientific and educational civilian institutions and organizations must be maintained at the engineering research, design, operational and educational levels. This liaison should be effected so as to directly and continuously benefit the Navy in its various technical bureaus, in its engineering laboratories, in its engineering training of midshipmen, and in its professional advancement of Regular and Reserve engineering officers.

7. The full utilization of the best engineering officers in the Navy, whether Academy or civilian college graduates, can best be accomplished by improving, in general, the lot of the technical man in uniform. He should not be considered as a convenient orphan nor should his promotion path to flag rank be any more statistically uncertain than for non-technical officers, regardless of his being Regular or Reserve.

8. In the Naval Service, at the level of actual engineering duty, clear distinction should be made between shipboard (operating) engineering duty, specialist engineering duty (such as radio, radar, fire-control, underwater sound, inter-communication, etc.), research engineering duty, design engineering duty, educational engineering duty, material engineering duty and procurement engineering duty. Rare is the man, let alone the Naval officer, who can do all these things well.

9. After *all* engineering officers have undergone a period of active, in-training ship duty (the duration of which should be consistent with their ultimate engineering duty objectives in the Navy), and after they have completed a suitable post-graduate course where necessary, they should be carefully differentiated. They should be differentiated according to aptitude, evident interest and performance, and categorized into the engineering specialty where they perform best and are most needed in the Service. Circumstances should be recognized which might justify subsequent change of category.

10. It would be well not to permit higher rank from one category to interfere directly with the performance of duties in another category. I am thinking, for example, of the particular case of engineering procurement experts attempting to responsibly establish the detailed objectives of a Naval research or

development project. A more extreme case to be obviated is any attempt by ship operators, who surely have their own hands full, to do more than define the operational requirements of new weapons, devices or shipboard engineering equipments.

11. Centralize in one agency responsibility for and authority to direct all Naval research and development of new weapons, devices, and equipments, in order to effect dispatch and coordination in the attainment of the technical objectives. The Head of this agency should report directly to the Secretary of the Navy and speak with his authority. (Since first writing this, the new Office of Research and Inventions has been established.)

12. Perpetually recognize that true progress in Naval engineering research, design and development is the keystone of strength and superiority in Naval warfare. ("Ex scientia tridens").

13. Maintain up-to-date at all times a set of organizational plans, based on current technological progress and upon various sizes of Naval engineering organizations, to serve as blueprints of whatever size and scope a shore technical structure may be required in time of national emergency.

14. Maintain a vigorous program of commissioning, categorizing, and promoting qualified engineering civilians in the Naval Reserve. Determine in advance of any national emergency and maintain on a current basis, the prospective billets where, on active duty, each Reserve Officer and his qualifications would be utilized to the maximum advantage of the Naval Service. Determine, in particular, whether or not it is to the best interests of the Navy that, in time of national emergency, he remain in his civilian engineering status or be ordered to active duty in Naval engineering.

No doubt, these observations and suggestions, as well as many others, have been made and are receiving the consideration they are deemed to merit. From that I am sure engineering in the Navy as seen by this Reserve officer will benefit. The ultimate general good of the Service requires much large-scale critical self-examination not later than *now*. That, too, represents progress in finding "the practical solution to the practical problem" of continued future growth and preparedness of the United States Navy.

SHIP'S LIGHTING AND DARK ADAPTATION.

By B. F. Greenberg.*

I—Introduction.

Dark adaptation is, as the name implies, the process of adjusting one's eyes for seeing when there is very little light, i.e., under very low levels of illumination. The average individual encounters the process of dark adaptation several times per day and no special means are provided to meet the problem. However, for shipboard application where time is important, the basis for a dark adaptation can be focused on one condition, namely,—*The least practical time required to be able to see the enemy or operate guns, etc., in the dark after coming from a lighted compartment or space.* It is to this condition that all attempts to devise a dark adaptation system are directed.

In the design of a low level illumination system dark adaptation is one factor. Depending upon the space or compartment under consideration, dark adaptation, light security or comfort may be the determining factor. However, for the purpose of this report the other factors will be neglected and only dark adaptation will be considered.

II—Mechanics of Seeing.

There are two mechanisms for seeing; one for seeing under low levels of illumination, which can be called night vision (technically known as rod vision because of the shape of the nerve cells); and day vision, for seeing under all levels of illumination except the very low values (cone vision). Each classification differs in respect to sensitivity, effect of color, ability to match colors (contrast sensitivity) and the ability to discern detail (acuity). And, as can be expected, the results of any dark adaptation experiments can be divided into two classes, depending upon the range of illumination values considered. Expressed

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mathematically, the relation between dark adaptation and illumination is a discontinuous function with the break occurring at a value of illumination equivalent to that obtained on a moonlit night (.01—.001 foot candles).

The process of becoming dark adapted is a gradual process. It takes an interval of time to see an object, if the illumination to which the eye is originally adapted is greater than the illumination on the object in question. This interval of time may be a second, or a few hours, depending upon the difference in illumination values, and the range of illumination values considered. For instance, if the illumination values are within the range of day vision (cones) then the time may be a matter of seconds, and the maximum time is in the order of one minute. If the range of values involves a change from day to night vision then the change in time for white light may be from about thirty minutes to a few hours.

Becoming dark adapted is a chemical process, and involves the accumulation of chemical substance, (visual purple). The substance is produced at a certain rate, and the sensitivity of the eye at any time is proportional to the amount of substance present at that time. The longer the time after exposure to a light source, the greater the amount of substance collected, and the greater the sensitivity of the eye. However, upon exposure to light the chemical substance becomes used up at the same time as it is being produced. Thus, when looking at a light source, two simultaneous processes are occurring, the eye is both producing and using up this chemical substance. When viewing a steady light source, equilibrium conditions are obtained, and the rate of loss is equal to the rate of gain. Now, if the light source is removed the accumulation of chemical substance still continues, as it is a chemical process, while the destruction of this substance is stopped, because it depends upon light. The amount of substance present at the instant the light source is removed depends upon the brightness of the light source. For high brightness the value is low, while for lower brightness a greater amount of substance is initially present.

Based on the above analysis, the following qualitative data on dark adaptation can be obtained:

(a) In order to see an object at a given brightness, level a certain amount of time is required.

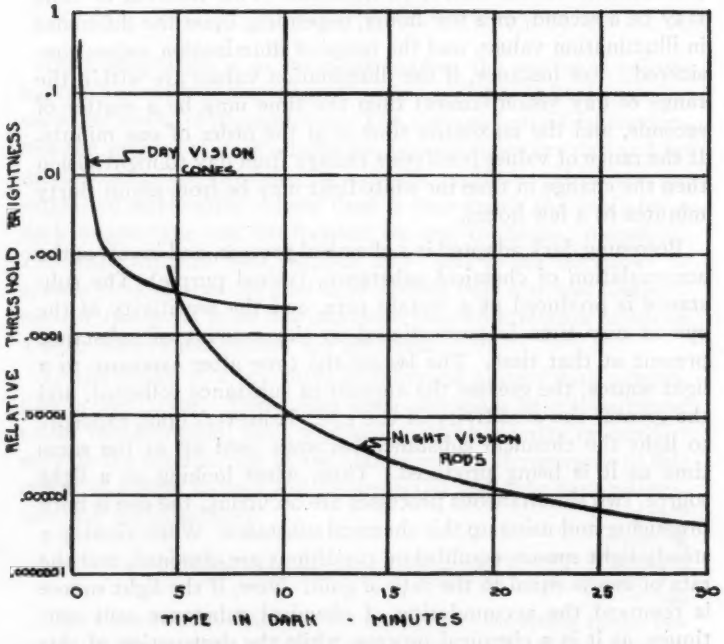


FIG I - DARK ADAPTATION RODS AND CONES

(b) The amount of time depends upon the illumination level to which the eye was previously exposed.

(c) During the time interval in which the eye is becoming dark adapted, exposure to a bright light source should be avoided. The effect of light is to destroy the light sensitive substance.

(d) The delay in dark adaptation caused by light exposure during the dark adaptation period depends upon the brightness and duration of the exposure. For relatively long exposures (greater than a few minutes), the chemical process would reach an equilibrium condition and the process of adaptation would have to be repeated.

(e) The effect of a short exposure is to cause a partial delay in adaptation. The length of the delay depends upon the brightness or rate of destruction of the light sensitive substance.

A typical curve of relative threshold brightness and/or illumination for both day and night vision is given as a function of time in Figure I, (A comparison between threshold illumination and threshold brightness is given in Appendix A.).

The relative threshold brightness for different initial illumination levels of white light as a function of time is shown in Figure II. From this curve it can be seen that with an initial, illumination of white light of 5 foot candles it takes 14 minutes to reach a relative threshold of 1 micro foot lamberts while for an initial exposure of 50 foot candles it takes 20 minutes to reach the same threshold.

III—Effect of Color on Dark Adaptation.

We have previously discussed three factors affecting dark adaptation: (1) amount of light required to see (threshold brightness), (2) the initial level of illumination previously exposed to (illumination level of initial stimuli) and (3) the permissible maximum time to see the threshold brightness (time). The fourth factor is (4) color.

It is a well known fact that the eye is not equally sensitive to energy of different wave lengths, i.e., all colors of light. For example, for day vision it takes 10 units of red (wave lengths 6500 Angstroms) to produce the same seeing effect as 1 unit of

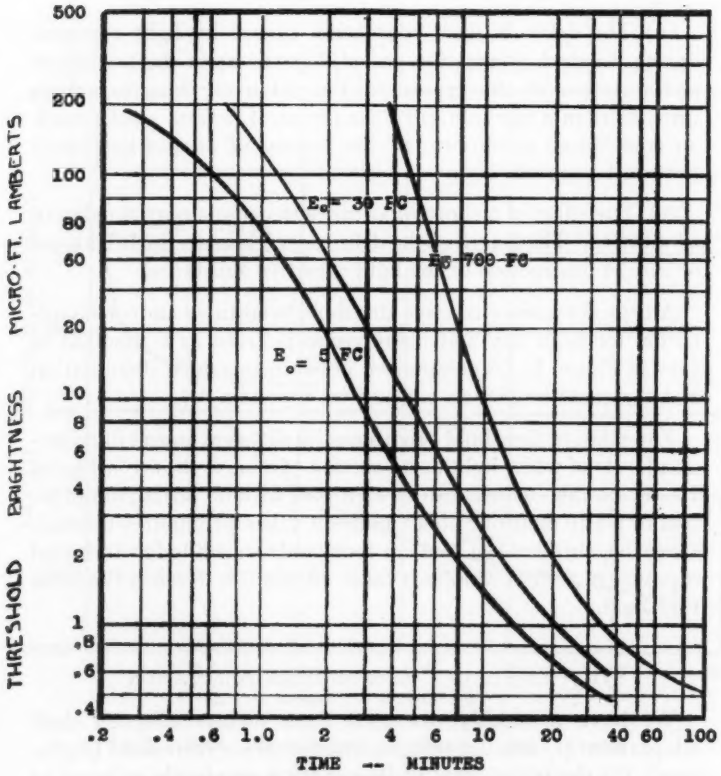


FIG. II -Effect of Initial Exposure To White Light On Dark Adaptation (Ref. b)

green (5500 Angstroms). For night vision, 160 units of red (6500A) produce the same seeing effect as 1 unit of green (5500A). The relative sensitivity of the eye to different colors is shown in Figure III.

The significant features which can be derived from this curve are as follows: (1) under night vision the eye is most sensitive to blue light, while for day vision the maximum sensitivity is obtained with green light; (2) night vision is much more sensitive than day vision; (3) under night vision the eye is relatively insensitive to deep red light.

Consider the first factor. Because the sensitivity of the eye varies with color, a small amount of blue light is required to be just seen, while a relatively large amount of red is required in order to be just seen. In general, the amount of light required to be seen at any wavelength is inversely proportoinal to the sensitivity of the eye at that wavelength. Thus, the greater the sensitivity (Figure III) the less light required to just see a light source. Now, since the threshold brightness varies with color, and the threshold varies with time, it follows that the adaptation time varies with the color of the light source. The rate of adaptation to a monochromatic light test source is shown in Figure IV.

The second important factor which can be derived from the visibility curve is the effect of the color of the initial stimulus on the adaptation time. In this case it can be assumed that the color of the test source is kept the same, and the illumination level of the initial stimulus is the same; the only variables are, then, the color of the initial stimulus and time. From Figure III it is evident that red light is the least sensitive to night vision, yellow next, then green, blue-green, and blue, in that order. The initial light exposures are in most cases viewed under day vision (cones), while the threshold values are usually in the range of night vision (rods). In the case of red light, from Figure III under day vision enough light could be provided for seeing without greatly affecting seeing under night vision. In other words, the eye is relatively blind to red light under night vision, but it can see with red light under day vision. Consequently, less time is required to become adapted after exposure to red light than to any other color. Similarly, orange light requires the next shortest time, green next, and finally initial exposure to blue light requires the longest time to reach a given threshold

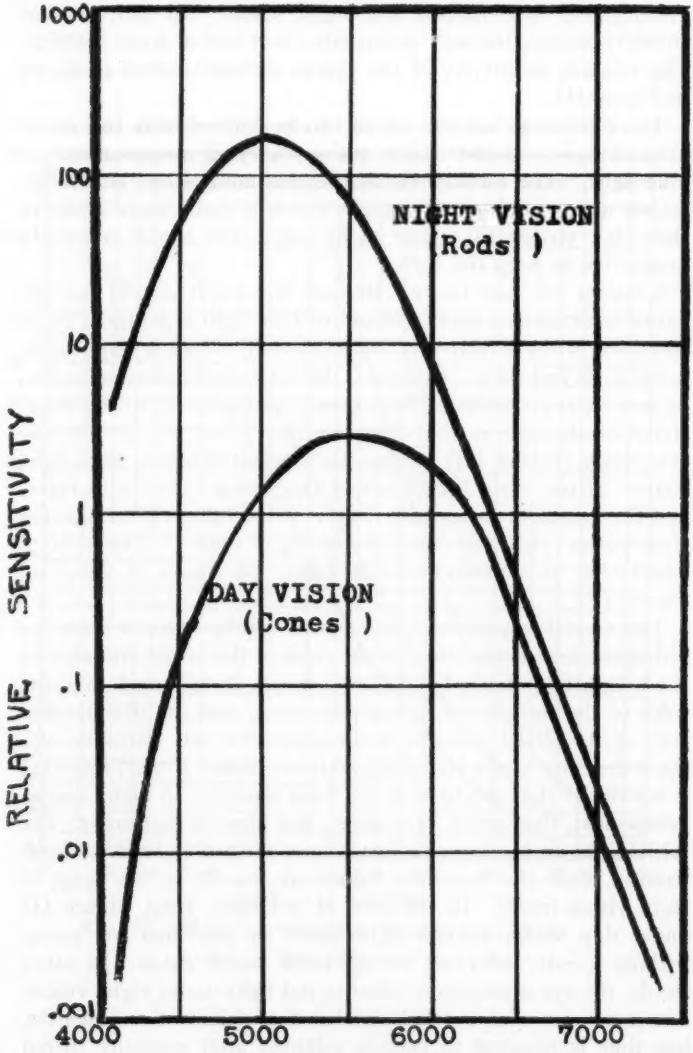


FIG. III- SENSITIVITY, DAY and NIGHT VISION -- (Rods and Cones)

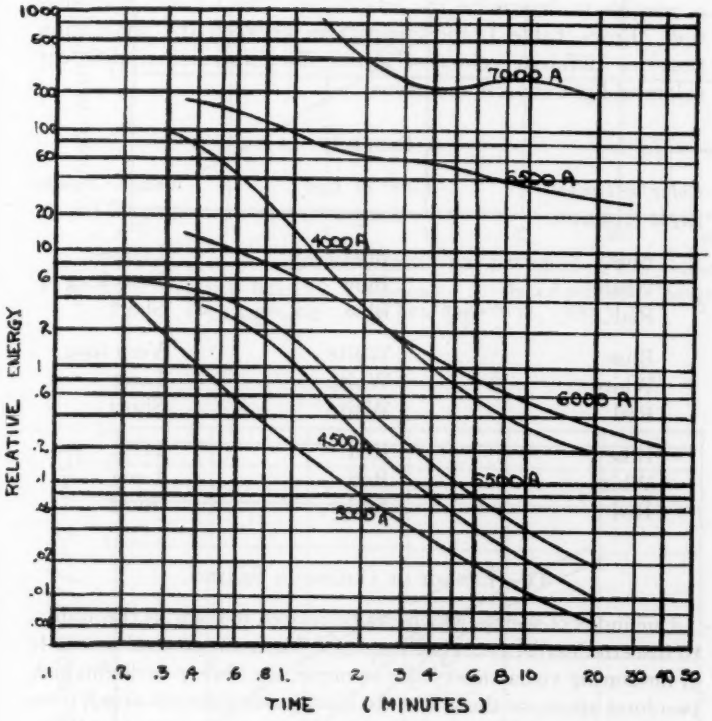


FIG. IV. RATE OF DARK ADAPTATION TO MONOCHROMATIC LIGHT (Ref. b)

value. The time required to reach a given threshold value after exposure to various colored light source depends upon relative sensitivities of the particular color under day and night vision.

From the above comparisons of adaptation time as a function of color of test source for a given color of initial stimulus, and adaptation time as a function of color of the initial stimulus, it is possible to determine the adaptation time for any combination. From Table I, the comparison between the adaptation time for different colors of initial illumination and different colors of light sources are given.

TABLE I.

Color of Initial Light Exposure	*Color of Test Source*	*Relative Adaptation Time*
Blue	Blue	Longest
White	Blue	Very long
Red	Blue	Short
Blue	White	Very long
White	White	Long
Red	White	Short
Blue	Red	Long
White	Red	Long
Red	Red	Short

IV—EFFECT OF COLOR ON SEEING.

One index of seeing, which can be related to color, is the ability to discern details, i.e., visual acuity. There are several methods of measuring visual acuity, for example, the ability to distinguish two lines apart, or the ability to distinguish different size letters on a test chart. Visual acuity is a function of many variables, namely: age of the observer, diet, illumination level and color. Disregarding the factors of age of the observer, and diet, etc., then visual acuity can be compared for different illuminations and colors. The first case to be considered is day vision. Under "day vision" visual acuity varies with illumination level, and, for a given illumination is the same for all colors. The relation between visual acuity and illumination for all colors is shown in Figure V.

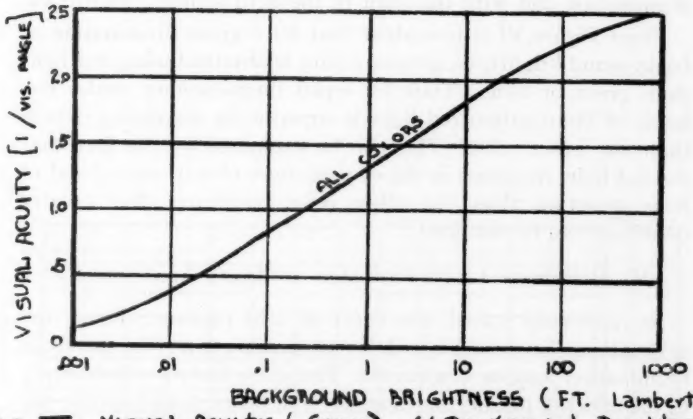


Fig. V Visual Acuity (Cones) f' Background Brightness (R.J. Lythgoe. Med. Res. Report, 173, 1932)

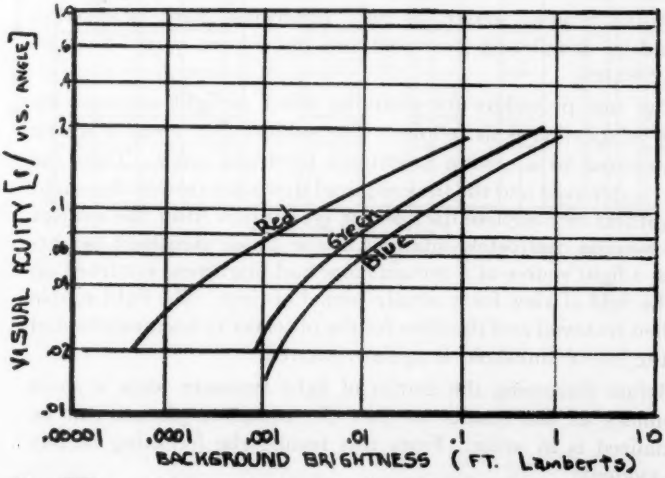


Fig VI VISUAL ACUITY f BACKGROUND BRIGHTNESS (Ref f b)

For night vision (rods) the visual acuity varies both with illumination and with the color of the light source. Figure VI.

From Figure VI it is evident that for a given illumination or background brightness, greater acuity is obtained using red light than green or blue. Thus for equal illuminations, under low levels of illumination red light is superior for discerning details than any other color. This can be explained by the fact that the red light receptors in the eye are more closely spaced and of finer structure than the other color receptors, thus greater definition can be obtained.

V—Effect of Light Exposure on Dark Adaptation.

As previously stated, the effect of light exposure during the dark adaptation period is to delay adaptation to a given threshold illumination and/or brightness. The same factors which apply to the effect of initial conditions on adaptation time apply to the effect of light exposure on adaptation time. For instance, the effect of light exposure depends upon the brightness and color of the source, the color and size of the test source, etc. For very low levels of illumination the effect of a colored light may be actually to decrease the adaptation time, while for longer exposures to a light source of high brightness dark adaptation would be completely destroyed and the process would have to be repeated.

The test procedure for studying effect of light exposure on dark adaptation is as follows: The subject first views a screen illuminated to a certain brightness level and color. Then the light is removed and the time required to reach a certain threshold brightness in complete darkness is measured. After the subject has become completely adapted to the given threshold brightness, a light source of a certain color and brightness is turned on in the field of view for a certain period of time. The light source is then removed and the time for the observer to become adapted to the initial threshold is again measured.

Before discussing the details of light exposure tests, a short summary of the results so that the complete picture can be visualized is in order. From test results the following factors are evident:

(A) For very low levels of illumination and/or brightness (approximately .001 F. C.) and for exposures of the order of

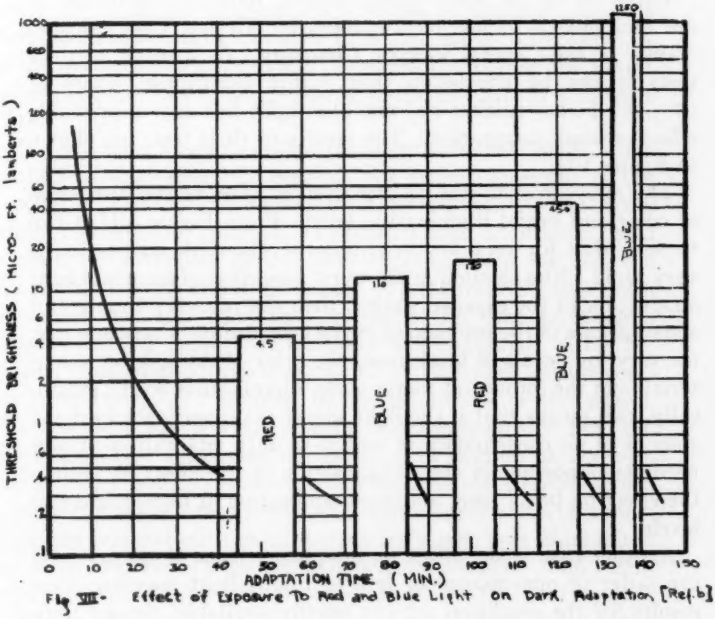


Fig VIII- Effect of Exposure To Red and Blue Light on Dark Adaptation, [Ref. b]

10 minutes, neither red, green, or blue light has an appreciable effect on dark adaptation.

(B) Instantaneous exposure to light sources, such as gun flashes, etc., increases adaptation in the order of a few seconds.

(C) Exposure to white light sources for about 15-30 seconds, increases adaptation time several minutes.

(D) Exposures to light source for several minutes results in complete light adaptation and the dark adaptation process has to be repeated.

Exposure to low level (approximately .001 foot lamberts) of red and blue light has been studied by Messrs. Luckiesh and Taylor of the General Electric Company. As a result of their tests it can be concluded that within brightness ranges of (0—.001 F. L.) neither red nor blue light has any appreciable effect on dark adaptation. The results of their tests are shown in Figure VII.

The above results can be explained in view of the discussion of color and initial illumination level. From Figure VII it can be seen that for very low brightness levels, dark adaptation is very rapid. Now, assuming the worst case, that of complete light adaptation to the exposed source, then the recovery time is but a special case of the problem of initial adaptation. Consequently, for very low levels of brightness, the color of the light is immaterial, and the important factor is the illumination level. Practically, this means that if the light source is properly shielded the color is of no consequence in regard to dark adaptation. Color becomes important in the consideration of the effect on seeing, the effect on being seen, and dark adaptation at high brightness levels.

Another case is the effect on adaptation time of exposures of the order of one minute or less to bright light sources. Test results for the condition are not readily available, though indications are that for brightness levels such as obtained from the general illumination system, the delay in dark adaptation for exposure of one minute or less is in the order of several minutes.

VI—Quantitative Results.

In order to compare two sets of measurements, the test procedures in both cases must be the same, i.e., the test source should be the same color, the initial stimulus must be the same, the size and distance from the test source should be the same, back-

ground brightness equal, etc. Therefore, before any comparisons can be made, a method of converting the variables to a common basis must be derived. In Appendix A, a method of reconciling test results is shown. This general method is founded on the basis of threshold illumination. Threshold illumination is defined as "the minimum illumination at the eye of the observer from a light source, in order to just perceive the presence of the light."

The threshold illumination is a function of the size, position, color, and background of the light source. The method of calculating the threshold illumination is shown in Appendix A. The threshold value can be calculated for any set of test results, if all the test procedures are given. Knowing the highest and lowest values, the results can be compared to the general curve, Figure VIII.

The following example illustrates the effectiveness of the above method in analyzing test results. An article appeared in the Journal of The Optical Society of America, ref., in which the author claimed that color has no effect on dark adaptation; that instead, the decreased illumination resulting from the use of a colored filter is the important factor. To substantiate this claim an experiment was conducted in which the time to reach a threshold of 3.5 micro foot lamberts was measured. After becoming dark adapted, the observer viewed a screen until becoming completely light adapted to the brightness of the screen. The test field was a white screen (color temperature 5400 degrees K) which subtended an angle of 12 degrees at the eye. The average time to reach the threshold (after viewing screen with brightness of 3 foot lamberts of white light) was 63 seconds, while the adaptation time after viewing screen was illuminated the same brightness with red light was 60 seconds. The calculated threshold illumination for this case is 1.6×10^{-7} foot candles, and from Figure VIII the equivalent time in seconds for red is 50 seconds and for the white is 110 seconds. If the threshold were changed to .35 micro foot lamberts then the threshold illumination would be equal to 1.6×10^{-8} foot candles and the equivalent time would be 500 seconds for white and 180 seconds for red.

In applying the above results to Naval practice, it is necessary to assume the possible minimum threshold which would possibly be encountered. Upon this value depends the relative advantages between different colored lights and the advisability of providing

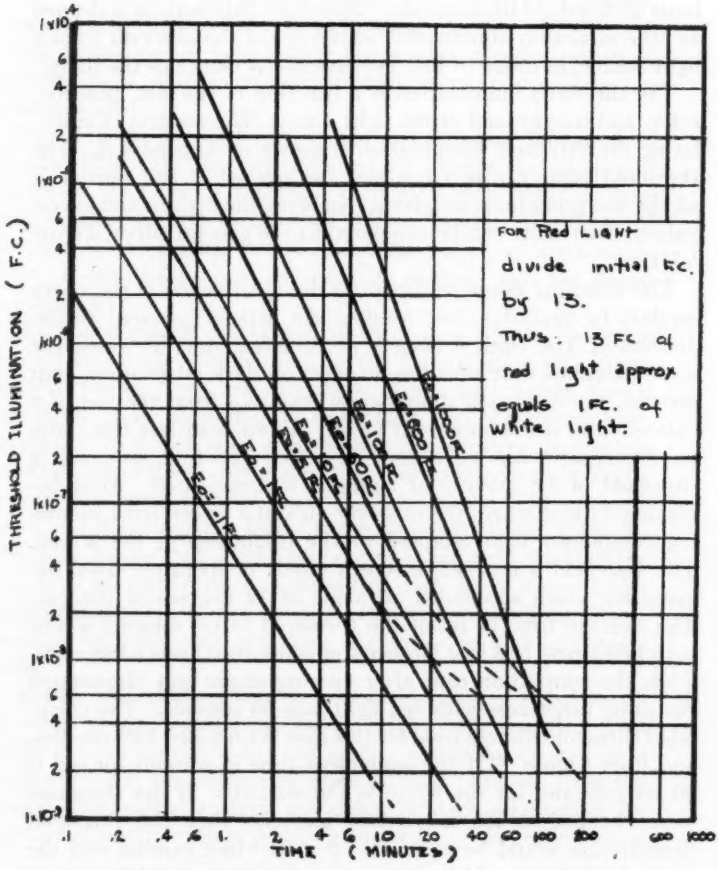


FIG VIII - THRESHOLD ILLUMINATION f INITIAL LIGHT EXPOSURE

a separate system. A reasonable estimate of threshold illumination encountered for seeing tasks under night time conditions is 1×10^{-8} foot candles.

VII—Types of Dark Adaption System.

Before attempting to answer the question of whether a dark adaptation system is advisable on shipboard, it is important to review the possible types of systems.

There are several different types of dark adaptation systems, each of which has its particular advantages and disadvantages. The major classifications are:

(a) Complete dark adaptation, separate from general illumination system.

(b) Partial system, combined with general illumination system.

(c) Two sets of light controls on general illumination system.

(d) Part complete and part general illumination system.

The first type of system, a complete dark adaptation system, should be provided when it is imperative to precondition all personnel for maximum night vision and to maintain that condition once it is obtained. In this case red light should be provided as it affects dark adaptation least. The level of illumination produced by red light should be kept to a minimum, with all sources of bright light excluded. However, enough light should be provided to insure safety. It should be possible for personnel to go out on exposed decks without becoming subjected to white light. This means that red light must be provided in all spaces and compartments which dark adapted personnel might enter. The advantage to this system is that at any moment personnel are conditioned to seeing without a wait on going into the darkness. The disadvantages of the system are: the high cost, use of materials and labor, complexity of an additional system, and the decreased seeing efficiency resulting from the use of the very low levels of illumination.

The second type of system is the partial system, obtained by combining the dark adaptation system with the general illumination system. This system is based on an allowable wait in becoming dark adapted. The system can be compared to a complete red light system by determining the increase in time required to become adapted to an assumed threshold with a given color, and illumination level. The permissible difference in time varies for different compartments, and so too the means for obtaining the

illumination varies with the compartments. The advantages of this type of system are decreased cost and improved seeing by nature of the increased illumination.

The third type of system is that obtained by switching sections of the general illumination system. In this case the same light source is used for the dark and for the general illumination system. For example, if the permissible increase in time were 2 minutes, then 2 foot candles of white light could be provided instead of red; and the general illumination in the compartment could be arranged so as to obtain two foot candles or five, depending on the specified value for that compartment. This system has the advantages of the least possible cost, and the minimum use of materials.

The fourth type of system is the partial red light system, designed so as to provide: a limited number of established routes between the berthing spaces and the topside watch stations, and a reduced light contrast between the interior of the vessel and the dark outside deck so that the period of blindness experienced by ship's personnel going to stations on the outside deck will be reduced to a minumum. The advantage of this type of system is the few red light fixtures required. The disadvantages of this system is that on going from inside lighted spaces to the outside the so-called blindness would be almost as great as the blindness on going from the white lighted spaces inside to the red lighted spaces.

There is no short cut to dark adaptation. On going from the white lighted spaces through red lighted spaces to the outside, the only gain by the use of the red light is a very small saving in time. The saving in time is equivalent to the time spent in the red light, Assuming that the length of the red lighted passage is 100 feet. then the savings in time would be of the order of 8 seconds. Thus the same effect could be accomplished by waiting outside 8 seconds. Contrary to the common belief, changes in brightness are not directly proportional to change in pupil size. For instance, pupil diameter changes through a ratio of 16 : 1 for brightness ranges of 1000 : 1. Thus the change of pupil size has little effect on producing temporary blindness. In view of these facts, it is questionable whether any advantage can be obtained by the use of a limited number of red light fixtures in certain selected passageways only.

VIII—Elements of System Design.

In the design of a dark adaptation system, as in the case of all other types of illumination systems, consideration must be given to such factors as: desired illumination levels, fixture spacing and mounting height, high brightness contrasts, etc. The same criteria for fixture spacing, light distribution, and elimination of glare which apply to the installations of a general illumination system apply to the design of the dark adaptation system.

The first element in system design to be considered is the illumination level. For any space or compartment the illumination level is dependent upon the nature of the seeing tasks carried out in that compartment. The illumination level is, then, a compromise between improved seeing, increased cost and use of materials. For dark adaptation systems another factor enters the problem. This factor is the effect of different illumination levels on dark adaptation. All other things being equal, the illumination level resulting from the use of red light should be the same as obtained from the white light installation. However because of the inefficient red light sources, high levels of red light are impractical to obtain and a compromise value must be assumed.

In order to obtain the same illumination with red light as obtained with white light, the number of red light fixtures in a compartment would have to be eight times the number of white light fixtures. Since this would result in an unduly large amount of red light fixtures, improved seeing has to be sacrificed to decreased cost and use of materials. Accordingly suggested values of red light illumination levels are given in Table II along with the specific illumination levels for white light.

In the table it should be noted that wherever reading is likely to be done, the illumination level is greater than .3 foot candles.

The second element in system design is the required fixture spacing. This factor is governed by the illumination within the compartment. The spacing required to obtain the illumination values given in Table II is given in column 4. In order to obtain the best distribution of light, the fixtures should be mounted as high as is practical. Low level bulkhead mountings should not be used as they concentrate the light over a comparatively small area.

TABLE II.

Compartment	*Foot Candles White*	*Red*	*Area/50w. red fixture*	*Spacing √A*
Air Officers' conference room	10	1.0	16	4′
Mess rooms, pantries.....	5	.5	32	6′
Staterooms.....	5	.1	130	12′
Crew's berthing.....	5	.25	64	8′
Hanger spaces.....	8	.8	26	5′
Gun mounts.....	2	.5	30	5′
Lounges, wardroom.....	5	.5	32	6′
Passages.....	2	.2	60	5 x 12′
Ready rooms.....	10	1.0	16	4′
Topside enclosed spaces...	5	.5	32	6′

The third element in the system design is brightness contrast, i.e., glare. All visual characteristics depend upon the illumination at the eye, which in turn is dependent upon the brightness and brightness distribution in the field of view. If a light is mounted in the field of view, dark adaptation time is dependent upon the brightness of the light source, rather than upon the illumination in the compartment. Therefore, for an ideal system, all bright sources should be removed from the field of view.

IX—Cost Analysis of Dark Adaptation System.

All other things being equal a complete dark adaptation system could be provided by the use of red light. A relatively high level of red light could be provided for seeing and still the adaptation time would be at a minimum. On the other side of the ledger, the use of materials, and the costs attendant on a complete and consistent dark adaptation system would be high in comparison to other types of systems. In the following discussion, cost, and use of materials, labor, time, etc., will be assumed as the critical factors.

As shown in Figure VI, for low brightness and/or illumination levels, different colors produce different visual acuities, (ability to distinguish detail). The relative illumination required for the same visual acuity for both high and low levels of illumination is given in Table IV.

TABLE III.

Relative Cost of Light (1/lumens 1 watt)

Color	*Incandescent*	*Fluorescent*	*Sodium*
White	1	.4	..
Red	8 (Filter 12%)	4.5	..
Yellow	2 (Filter 50%)	.8	.3
Blue-Green	12 (Filter 8%)	.4	..

TABLE IV.*

Relative Visual Acuity (ability to distinguish details).

Color	*High Brightness*	*Low Brightness*	
White	Constant	3.0	*Rating refers to
Red	Constant	1.0	required relative
Yellow	Constant	1.7	illumination for
Blue-Green	Constant	4.0	same visual acuity.

Table III can be combined with Table IV to obtain the relative cost for the same seeing ability. The results of this combination for different color light sources are shown in Table V.

TABLE V.

Relative Costs for Same Seeing Ability.

Color	*Relative Cost**	
White	1.0	*Values refer to low
Red	2.7	brightness values,
Yellow	2.2	and an incandescent
Blue-Green	16.0	light source.

From the above table it is evident that white light is least expensive, then yellow, red and finally blue-green and blue are most expensive. In order of effectiveness in reducing dark adaptation time it has been shown that red light is best, yellow next, green, white, blue-green, and blue is the worst.

Therefore, whereas a yellow light source is less expensive than red and as it only slightly increases the adaptation time, it follows that for some applications yellow light should be used.

Using yellow light, the seeing ability would be decreased by nature of the lower illumination, but the cost of the installation would be only $\frac{1.5}{4.0} \times \frac{2}{8} = 9$ per cent of the cost of the red light installation.

In many cases further savings can be obtained by the use of a color other than red, as enough light to preclude the need for a dual system could efficiently be provided. If necessary, the illumination level in the compartment could be decreased by the selective grouping of light control. Another alternative, which can be used in certain spaces and compartments, is the use of white light.

Type of Light Source.

In order to obtain a colored light source most efficiently, it is advisable to use a type of source which initially gives the desired color. This avoids the necessity of using a filter which transmits the desired color and absorbs all others. The available types of light sources which were considered are: incandescent, fluorescent and neon. The luminous efficiency (lumens per watt) of these types of light sources in producing red light, such as now specified for a dark adaptation system (Cutoff at 6200 Angstroms) follows:

Table VI.

Light Source	*Luminous Efficiency*	*Relative Cost*
50 watt incandescent	1.2 lumen per watt (red)	1.00
15 watt fluorescent (pink)	3.3 lumen per watt (red)	.36
225 watt neon	14.0 lumen per watt (red)	.09

From the above table it is evident that sources other than a filtered incandescent lamp are more efficient in producing red light. In other words, taking the same type color filter and placing it over an incandescent, fluorescent and neon light source, the relative light output per watt would be 1.2, 3.3, and 14 lumens per watt respectively. Thus, particularly where a relatively high level of red light is desired, a source other than incandescent lamp should be used.

X—Shipboard Application.

In any type of installation only those spaces which require a dark adaptation system should be provided with it. Accordingly, the possible spaces in which personnel requiring dark adaptation are likely to enter can be classified into five categories:

(a) Air officer's conference room; ready room, hangar space.
(b) Crew's berthing and messing, wardroom, stateroom.
(c) Topside enclosed spaces, sea cabin, radar space, conning tower.
(d) Chart house, gun mounts.
(e) Passageways.

In each of the above spaces a comparison will be made between two types of systems; a complete adaptation system and a partial system based on an allowable wait in becoming dark adapted. Each group and space will be considered separately and the estimated cost and effectiveness of each system compared.

A. Complete Dark Adaptation System.

Group a. Air officers' conference room, ready rooms and hangar space.

In these spaces it is particularly important to have enough lights for the efficient performance of the required tasks. From Table II the recommended illumination in air conference rooms, ready rooms and hangar spaces is 1, .8, foot candles respectively. In order to obtain the recommended spacing the fixture spacing in the conference room and ready room should be 4 x 4 feet, and in the hangar spaces it should be 5 x 5 feet.

Group b. Crew's berthing and messing, wardroom and stateroom

In these spaces the seeing tasks are not critical, and in order to minimize costs, the illumination levels should be kept at a minimum. The recommended illumination levels are:

Crew's berthing and messing.....	.25 foot candles
Wardroon.....	.5 foot candles
Staterooms.....	.1 foot candles

The fixture spacing required to obtain these values are:

Crew's berthing and messing	8 x 8
Wardrooms	6 x 6
Staterooms	12 x 12

Group c. Topside enclosed spaces, sea cabin, conning tower, radar spaces.

In topside enclosed spaces and sea cabins the recommended illumination is .5 foot candles. The spacing to obtain this value is 6 × 6 feet.

In radar spaces, a dark adaptation system may or may not be necessary depending upon the location and the use of the space. If dark adaptation is required then the lighting in the space should be consistent. The radar screens should preferably be red or yellow and of such brightness as not to increase adaptation time. Red light fixtures in the compartment, if nearer than 12 feet from the radar screen should be provided with a shield to prevent direct light from falling on the screen and thus reduce the contrast on the screen.

Group d. Chart house and gun mounts.

In these spaces enough red light should be provided for efficient operation. A relatively high level of red light should be provided over the chart table, and the maps and charts should be printed in such colors which could best be seen under red lighting. In gun mounts the maximum light should be provided at the gun breech, and fixtures arranged so as to avoid glare. The recommended illumination level in the gun mounts is .5 foot candles of red light.

Group e. Passageways.

Red light should be provided in passageways through which personnel pass on going on decks. The fixtures should be arranged to provide safe passage and to illuminate coamings of access doors, hatches, ladders, etc. In general the fixtures should be spaced 12 feet apart and mounted on the overhead.

B. Partial Dark Adaptation System.

Group a.

The recommended illumination in ready rooms and air officer's conference rooms for the partial dark adaptation system is 5 foot

candles of yellow light. The specified value of general illumination in the above space is 10 foot candles; therefore, by controlling the fixtures providing the general illumination with two switches instead of one, both 5 and 10 foot candles could be provided. Using the system no addtional fixtures for the dark adaptation system need be provided. The yellow light could best be obtained by installing pink incandescent lamps. The lower brightness, higher efficiency and proper color of this type of source makes it more desirable than a filtered incandescent light source.

The other compartment in this group is hangar spaces. For the partial system, it is not advisable to provide a separate dark adaptation system in these spaces. The increased difficulties in handling planes would offset the advantage of a dark adaptation system. For those personnel who require dark adaptation, red goggles should be provided.

Group b.

Red light fixtures should not be provided in officer's staterooms. If dark adaptation is required then the berth light should be used. Assuming that direct exposure to the light source is avoided, then the increase in adaptation time resulting from the use of berth light is in the order of 1.5 minutes. If necessary the berth light fixture should be provided with a red shade.

Crew's berthing and messing spaces should not be provided with a red light system. Fixtures providing general illumination should be properly shielded and the switching arranged so that two foot candles can be provided. An alternate method for lighting crew's berthing and messing spaces would be to provide five foot candles of pink light. The need for separate switching would be avoided and the overall adaptation time would be decreased.

Group c.

In all cases topside enclosed spaces should be provided with red light. It should be possible for personnel on watch to go in and out of topside spaces without impairing dark adaptation.

Group d.

The chart house should not be provided with red light. The ability to read charts quickly and efficiently is more important

than the maintenance of dark adaptation of the navigation officers. If necessary a screen or shield should be provided between the chart house and other spaces.

Gun mounts should not be provided with a red light system. Rapid and efficient operation of the guns is more important than the maintenance of dark adaptation. If necessary a screen should be provided between the officers requiring dark adaptation and the remainder of the gun crew.

Group e.

Passageways should not be provided with a source of red light. The general illumination level of 2 foot candles results in an increase of adaptation time of 2 minutes. Since other spaces would not be provided with a dark adaptation system, very little could be accomplished by providing red light in passageways alone.

The above discussion illustrates the different degrees to which the dark adaptation system can be designed. However, whichever system is used, it is important to be consistent throughout, as any combination of systems would in most cases destroy the effectiveness of both types of systems involved.

REFERENCES.

(a) P. Moon, Scientific Basis of Illuminating Engineering. McGraw-Hill, 1936.
Presents a mathematical approach based on theory of chemical reactions, the method can be used to check test data.
(b) Luckiesh and Taylor, "Seeing at Low Brightness", I.E.S. Transaction. April 1943.
Test data on adaptation curves vs. Eo, given as a function of color of test source. Also, visual acuity at low brightness for different colored light sources is determined.
(c) Earl M. Lowry. Effect of Hue on Dark Adaptation. J. O. S. A. Nov. 1943. Pg. 619.
(d) S. Hecht. Equilibrium and Dark Adaptation in J. Gen. Physiol. 1, 1919, p. 545 (Journal of Gen'l Physiology) N. Y.
(e) S. Hecht. The Photochemical Nature of the Photosensory Process. J. Gen. Physiol. 2, 1920, p. 229.
(f) S. Hecht. The Dark Adaptation of the Human Eye, J. Gen. Physiol. 2, 1920, 499.
(g) S. Hecht. The Nature of Fotoal Dark Adaptation, J. Gen. Physiol. 10, 1921, p. 113.
(h) S. Hecht. The Kinematics of Dark Adaptation. J. Gen. Physiol. 10, 1927, p. 781.
(i) P. W. Cobb. Dark Adaptation with Especial Ref. to Problems of Night Flying. Phy. Rev. 26, 1919, p. 428.
(j) S. Hecht. Photochemistry of Visual Purple. J. Gen. Physiol. 3, 1920, p. 1, 285, 6, 1924, p. 731.
(k) From N. Nagel in Helmoltz, Vol. II. p. 320.

(l) Dark Adaptation of Retinal Field of Different Size and Location. J. Gen. Physiol. 19, 321, 1935.
(m) Dark Adaptation as Influenced by Intensity of Light Adaptation. J. O. S. A. 26, 304, 1936.
(n) Ibid.—J. Gen. Physiol. 20, 831 (1937).
(o) The instantaneous visual threshold after light adaptation. Prov. Nat'l Acad. Sci. 23, 227 (1937).

APPENDIX A.

Comparison Betewwn Threshold Illumination and Brightness.

Illumination can be defined as the luminous flux falling *on* a surface per unit area. The foot candle is the practical unit.

Brightness can be defined as the luminous flux emitted *by* a surface per unit area. The unit of brightness is the foot lambert.

If a surface reflects 100 per cent of the light falling on it, then for an illumination *on* the surface of 1 foot candle, the brightness equals 1 foot candle. For a reflection factor of 50 per cent, then an illumination of 1 foot lambert produces a brightness of ½ foot lambert.

A surface having a certain brightness produces a given value of illumination at any distance from the light source. The illumination resulting from a source of a certain brightness depends upon the size and orientation of the light source and the position of the test source. For example, the illumination E, from a source of brightness B, and area "A" a distance of D from the light source (where $D > > A$) is equal to:

$$E = \frac{BA}{\pi D^2}.$$

Thus a source with a brightness of 10 foot lamberts and an area of 1 square foot, produces an illumination of 320 microfoot candles at a distance of 100 feet from the source.

For any size and position of test source threshold brightness can be calculated in terms of threshold illumination from the above equation. When the distance from the source is small compared to the size of the source, a more complicated formula must be used.

The required amount of light at the eye of an observer to just see a test source depends upon the size, color, and position of test source. From references, the threshold illumination for different size of test source, color of test source and background brightness is given. From those values, the minimum threshold illumination or brightness can be calculated for any set of conditions.

SHIP'S SERVICE GENERATOR VOLTAGE REGULATOR AND EXCITATION SYSTEMS.

By R. B. Lisbakken.

With the advent in 1932 of alternating current power systems on Naval vessels, the problem of suitable automatic voltage regulator and excitation systems for alternating current generators became a problem not previously experienced on direct current generators. The problem initially was considered one of maintaining the A.C. generator voltage within close limits by controlling the A. C. generator excitation and of accepting the generator, exciter and voltage regulator performance characteristics as more or less separate from the power distribution system performance.

In recent years, increasing consideration has been given to coordinating the generating and the distribution system into a carefully integrated system. Since the individual loads on the system have a specific function to perform and therefore must be supplied with a properly regulated voltage, the control of that voltage should be undertaken in the generating system. Various other factors which have influenced changes in generator and regulator characteristics are the adoption of circuit breaker selective tripping, the application of fire control and radar equipment, shock and vibration considerations and weight and space requirements on Naval vessels. Each of these factors has been considered with the objective of obtaining voltage regulators and excitation systems as near ideal as possible consistent with other requirements.

Design Considerations.

The electrical characteristics which have been considered in determining the type of voltage regulator best suited for shipboard use are as follows:

(*a*) Voltage sensitivity (The maintaining of generator terminal voltage within specified limits from no load to full load including conditions of frequency variation, power factor variation, phase unbalance, inclined operation, severe shock and vibration.)

(*b*) Speed of response (The speed with which the regulator

operates to start correction of the excitation following a transient load change.)

(*c*) Inherent forcing ability (Ability to provide large corrective action to change generator excitation.)

(*d*) Inherent damping (Following application of corrective action, the ability to damp the corrective action to prevent overshoot of A.C. generator voltage without materially slowing down the initial recovery of the voltage.)

(*e*) Voltage recovery time (The total time for the generator voltage to return to and remain within the prescribed sensitivity limits following a specified sudden load change. The voltage recovery time is a direct function of the speed of response, forcing ability and damping of the voltage regulator and such characteristics of the exciter as field time constants, speed of response, stability and ceiling voltage.)

The mechanical characteristics which influenced the application of voltage regulators are as follows:

(*a*). Space and weight.

(*b*). Ability to withstand shock and vibration requirements without mechanical damage.

(*c*). Mechanically moving parts requiring repair and maintenance.

Regulator Types.

To clarify terminology used in the subsequent discussion of shipboard voltage regulator equipment, the prinicpal types of voltage regulators used on ship's service generators are identified as follows:

(*a*) Indirect acting rheostatic: This type consists of a voltage sensitive control device whose primary contacts control a motor-operated rheostat connected in the generator field circuit. The secondary contacts control the operation of contactors which short out the rheostat resistance or insert a large block of fixed resistance to raise or lower generator voltage for large changes of load. On all Naval applications, this type of regulator operates in the A.C. generator field and the exciter is a constant potential 120 volt D.C. generator. A typical circuit for an indirect acting rheostatic type voltage regulator is shown in Figure 1.

(*b*) Direct acting rheostatic: This type consists of a voltage sensitive device incorporating and mechanically operating a vari-

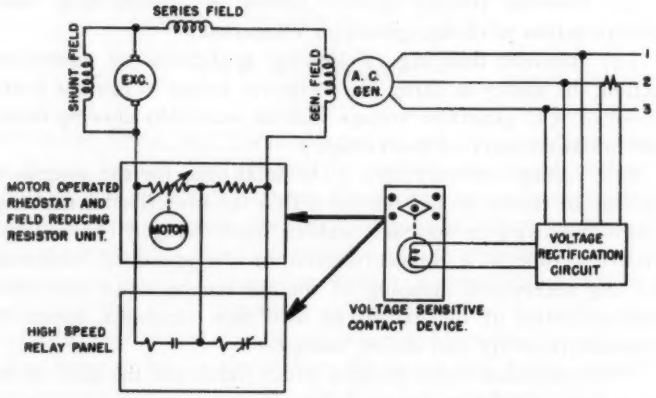


FIGURE 1.—SIMPLIFIED DIAGRAM INDIRECT-ACTING RHEOSTATIC TYPE VOLTAGE REGULATOR WITH CONSTANT VOLTAGE EXCITER.

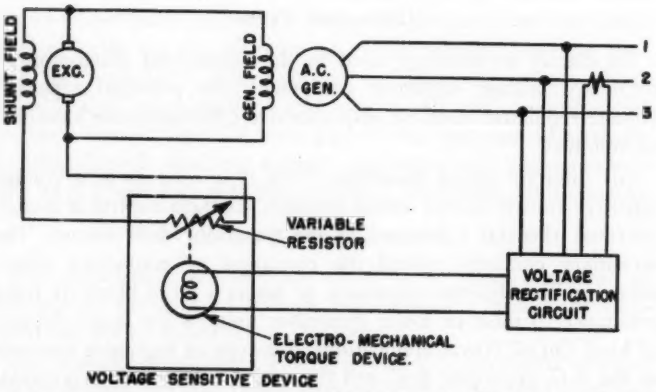


FIGURE 2.—SIMPLIFIED DIAGRAM DIRECT-ACTING RHEOSTATIC TYPE VOLTAGE REGULATOR WITH VARIABLE VOLTAGE EXCITER.

able resistance which is connected in the field circuit of a generator. The direct acting rheostatic type is usually connected in the exciter field circuit but may be connected directly in the A.C. generator field of small capacity generators if the regulator resistance has sufficient current capacity. When connected in the exciter field, the exciter becomes a variable voltage exciter operating normally between approximately 25 volts and 90 volts and having a ceiling of about 160 volts. A typical circuit for a direct acting rheostatic type regulator is shown in Figure 2.

(*c*) Rotary Amplifier: This type is one in which voltage control is obtained through a voltage sensitive static electrical circuit. The static circuit is made up of potential and current transformers feeding through reactors, resistors, condensers and dry disc rectifiers and employs no dynamic components. The output of the static circuit is amplified through a very rapid response exciter (usually having several specially designed fields) to control the A.C. generator excitation and hence the voltage. Simplified wiring diagrams of the several manufacturers' variations of the rotary amplifier type regulator are shown in Figures 4 through 7.

Regulator Application.

From 1932 to 1943, Navy practice provided that all ship's service generators and even emergency service generators, at first above 100 Kw. and later above 250 Kw., must use the indirect-acting rheostatic type voltage regulator. The direct-acting rheostatic regulator was applied only to small capacity emergency or auxiliary service generators. The direct-acting rheostatic regulator was not previously applied to ship's service generators, even though developed for a number of years, because this type regulator had not been tried and tested by the Navy to adequately determine its suitability on ship's service units.

However, to determine conclusively the comparative advantages of both the direct and indirect-acting rheostatic types of voltage regulators, tests were conducted during 1942 and 1943 both on shipboard and at manufacturer's plants on Navy 1250 Kw. ship's service generators. The results of all tests proved conclusively that the direct-acting rheostatic regulator was far superior in electrical performance to the indirect acting rheostatic regulator. Other advantages existed in the direct-acting rheostatic regulator

in that maintenance-requiring items such as relays and motor operated rheostats are not required, standard requirements for shockproofness were more readily met and the space and weight was less than for the indirect-acting rheostatic regulator. As a result, the indirect-acting regulator was supplanted by the direct acting regulator on ship's service and emergency generators on new construction and conversion vessels beginning in 1943. The direct acting regulator is now in service on battleships, carriers, cruisers, tenders and landing craft controlling generators from 60 Kw. to 1250 Kw.

During 1944, the third type of voltage regulator was developed for Naval application by the electrical manufacturers at the request of the Bureau of Ships. This type, the rotary amplifier voltage regulator, as used commercially, had indicated better performance and a more simple control circuit than either the direct or indirect-acting rheostatic types. To prove the electrical performance of this newest type regulator, various capacities of generators from 100 Kw. to 1500 Kw. were purchased having rotary amplifier regulator systems and tests were conducted at the manufacturers' plants. Because of having still better electrical performance and because of the apparent decrease in maintenance problems over the direct-acting rheostatic regulator, application of the rotary amplifier type regulator system to vessels where delivery of the equipment permitted was begun late in 1944. The vessels which have or will have this latest type regulator include battleships, carriers, crusiers, minesweepers and tenders with generator ratings ranging from 100 Kw. to 1500 Kw.

Test Results.

As an indication of the comparative performance under transient load conditions of the indirect-acting rheostatic, direct-acting rheostatic and rotary amplifier type regulators, the test results of a suddenly applied load test made on a 1250 Kw. Navy generator using each of the three types of regulators is shown in Figure 3. The comparative tests were all made by using an oscillograph to record the voltage for a sudden application of a load equivalent to 50 per cent of the generator rating at approximately zero power factor from an initial condition of no load. The maximum voltage dip and the time for the voltage to recover to, and remain within plus or minus 3 per cent of normal voltage

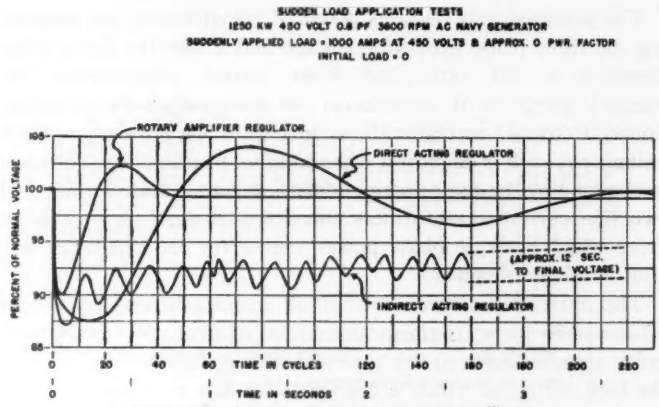


FIGURE 3.—SUDDEN LOAD APPLICATION TESTS.

on each of three types of voltage regulators of the same manufacture, is shown graphically in Figure 3 and tabulated below:

Type of Regulator	*Maximum Voltage Dip*	*Recovery Time To± 3% of normal*
Indirect acting rheostatic	13%	10 secs. (approx.)
Direct acting rheostatic	12.5%	2.6 secs.
Rotary amplifier	10%	0.2 secs.

ROTARY AMPLIFIER CIRCUITS.

Since the rotary amplifier voltage regulating system is one of the latest developments in shipboard regulators, particular attention will be given to a brief analysis of the salient characteristics of each manufacturers' equipment. During the initial development of this equipment, the requirement was imposed upon each manufacturer that the switchboard mounted rotary amplifier regulator components must mount interchangeably with the components of each other manufacturer. This has been accomplished quite successfully so that now the units making up the switchboard mounted regulator equipment to control one A.C. generator and exciter consist of the following:

Potential Unit.
Automatic Control Unit.
Voltage Adjusting Unit.
Manual Control Unit.
Control Switch ("Manual-Automatic").

The potential unit contains potential transformers for measuring the three phase generator voltage and a reactive droop compensation circuit (energized from current transformers for parallel operation of generators). In the case of the Westinghouse "Rototrol" regulator shown in Figure 5, a positive sequence voltage network is employed wherein three phase voltage response is obtained by the use of a single phase potential transformer and two line current transformers connected through an impedance from which a single phase power source for the regulator control circuit is obtained.

The automatic control unit of all manufacturers' equipment contains a frequency compensation circuit of a capacitor-resistance-inductance resonant circuit type and voltage comparison circuits, the final output of which is fed from dry-disc rectifiers to a field on the specially designed high-response exciter for the A.C. generator.

The voltage adjusting unit consists of a small hand-operated plate-type rheostat on all manufacturers' equipment except the General Electric Company regulator which uses an adjustable saturable reactor. The voltage adjusting unit is used only to adjust the voltage level which is to be held by the voltage regulator. Since the reactive droop compensation employed to obtain proportional division of reactive Kva load on paralleled generators introduces a voltage droop of approximately 4 per cent from no load to full load at 0.8 power factor, the voltage adjusting unit permits adjustment of the voltage from 3 per cent below to 7 per cent above the regulated voltage or such that plus or minus 3 per cent of rated voltage may always be obtained.

The manual control unit is a separate means of controlling the A.C. generator voltage in case of failure of the automatic control circuit (potential unit, automatic control unit and voltage adjusting unit). The manual control unit in all cases is a manually-operated plate type rheostat controlling the same field in the exciter to which the automatic control circuit is connected. In some cases, dry-disc rectifiers are included in the manual control circuit as a "valve" to prevent reversal of the exciter field.

The "Manual-Automatic" control switch serves to transfer from the manual control circuit to the automatic control circuit such that in either position the other circuit is de-energized.

In connection with the rotary amplifier type voltage regulator,

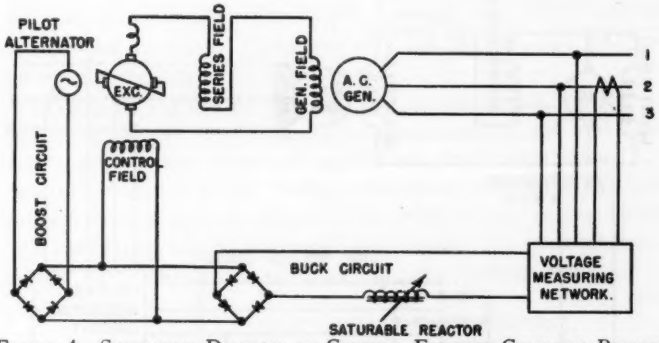


FIGURE 4.—SIMPLIFIED DIAGRAM OF GENERAL ELECTRIC COMPANY ROTARY AMPLIFIER TYPE ("AMPLIDYNE") VOLTAGE REGULATOR AND EXCITATION SYSTEM.

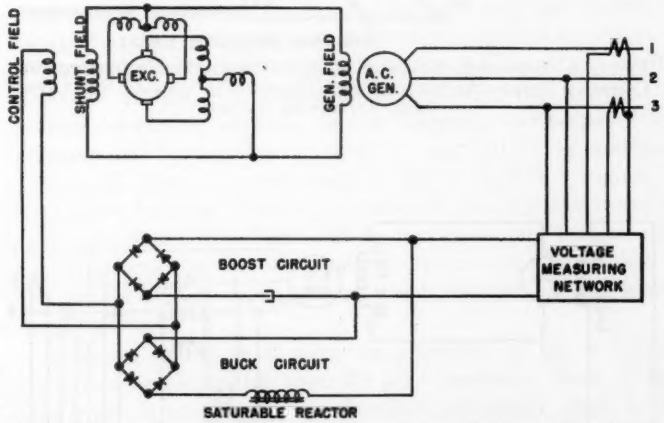


FIGURE 5.—SIMPLIFIED DIAGRAM OF WESTINGHOUSE ELECTRIC CORPORATION ROTARY AMPLIFIER TYPE ("ROTOTROL") VOLTAGE REGULATOR AND EXCITATION SYSTEM.

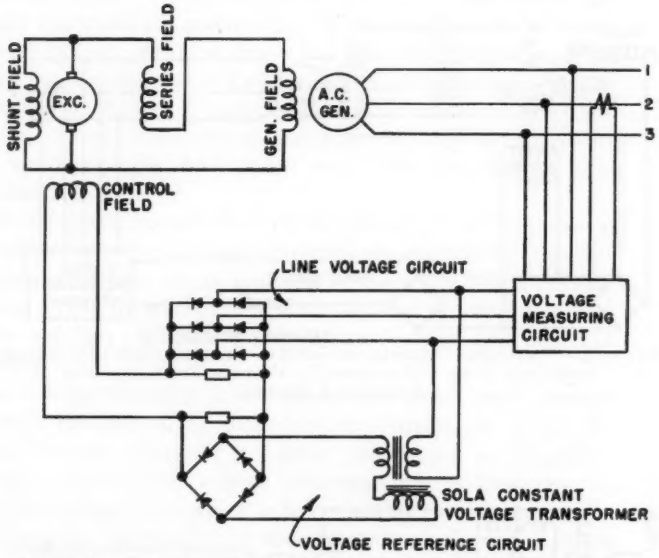


FIGURE 6.—SIMPLIFIED DIAGRAM OF ALLIS-CHALMERS MANUFACTURING COMPANY ROTARY AMPLIFIER TYPE ("REGULEX") VOLTAGE REGULATOR AND EXCITATION SYSTEM.

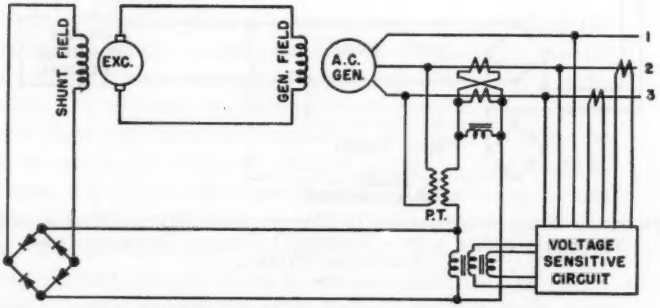


FIGURE 7.—SIMPLIFIED DIAGRAM OF DELCO-WARD LEONARD ROTARY AMPLIFIER TYPE ("STATICTOR") VOLTAGE REGULATOR AND EXCITATION SYSTEM.

it should be pointed out that while the General Electric and Westinghouse control circuits are different, the entire automatic control circuit of each of these manufacturers is identical, physically and electrically, for all capacities of Navy generators from 60 Kw. to 1500 Kw. The Ward Leonard and Allis-Chalmers equipments have been developed only for 60 Kw. and 100 Kw. generators to date.

In each of Figures 4 through 7, the potential unit, voltage adjusting unit and the frequency compensation circuit and other refinements of the automatic control unit have been lumped into one unit indicated as the "voltage measuring network". The basic voltage comparison circuits and the fields of the exciter which are controlled will be discussed individually for each manufacturers' particular system of rotary amplifier voltage control.

General Electric Company "Amplidyne".

Differing from the commercial form of "Amplidyne", the Navy type uses a small permanent-magnet rotating field alternator for a reference and initial build-up voltage source in lieu of a separate D.C. power source. This pilot alternator is on the same shaft as the A.C. generator and exciter and is rated 55 volts, 0.5 ampere, single phase. As shown in Figure 4 the pilot alternator furnishes power for the linear circuit rectifier which supplies a current to the control field in a direction to boost the A.C. generator excitation and voltage. The generator line voltage, fed through the voltage measuring network (hence frequency compensated and compensated for parallel operation) is applied to the nonlinear (saturable reactor) circuit rectifier which supplies a current to the control field in a direction to reduce the A.C. generator excitation and voltage. The linear and the non-linear rectifiers are connected in series so that the resultant direction of current flow in the control field is dependant on which rectifier has the higher output voltage.

Referring to Figure 8, when the generator voltage is normal, the linear circuit voltage from the pilot supplies a boost current OD which is in the opposite direction and nearly equal to the buck current OA supplied by the saturable reactor in the nonlinear circuit. Thus, the current through the control field is negligible and the exciter maintains the normal generator voltage.

However, should a load be thrown on the generator, the line

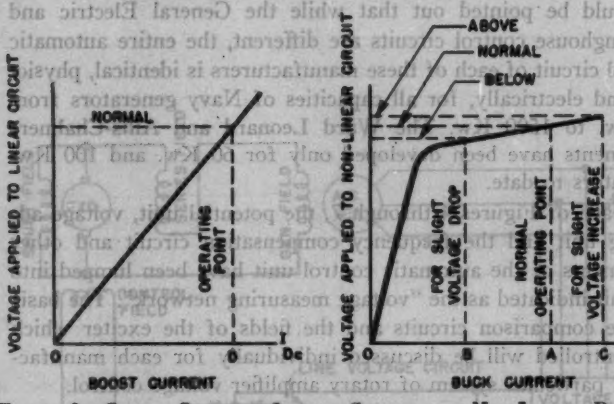


FIGURE 8.—CURVES SHOWING LINEAR CIRCUIT AND NON-LINEAR REACTOR CIRCUIT CHARACTERISTIC.

voltage would drop slightly and the buck current would drop considerably to a value such as OB. The result would be that a boost current equal to OD minus OB would flow in the control field to increase the excitation and terminal voltage of the A.C. generator. Conversely, should the A.C. generator voltage rise due to a removal of load, the non-linear circuit buck current would increase to a value such as OC. The resulting current in the control field would then be a buck current equal to OC minus OD which would reduce the excitation and terminal voltage of the A.C. generator.

The "Amplidyne" exciter will maintain the A.C. generator voltage for all rated load conditions within a normal operating range of between 0.1 ampere buck and 0.2 ampere boost current applied to the control field.

WESTINGHOUSE ELECTRIC CORPORATION, "ROTOTROL".

The Westinghouse "Rototrol" rotary amplifier voltage regulator system consists of a voltage measuring network and a voltage comparison circuit, the output of which supplies a buck or a boost current to the "Rototrol" exciter for correcting excitation and voltage of the A.C. generator for changing load conditions. The voltage comparison circuit consists of a capacitor-type linear impedance circuit and saturable reactor-type non-linear impedance circuit as shown in Figure 5. With normal A.C. voltage through

the voltage measuring circuit, the two impedances are equal, the rectifier voltages will cancel each other and no current will flow through the control field. Figure 8 may be used again to illustrate how a slight drop or rise in line voltage will cause a large boost or buck current to be applied to the control field to correct the A.C. generator excitation and voltage. As soon as generator voltage has been restored to normal, the linear and the non-linear impedance will again become equal and no current will flow into the control field until the next voltage change.

Allis-Chalmers Manufacturing Co. "Regulex".

The Allis-Chalmers "Regulex" rotary amplifier voltage regulation system employs an exciter having self-excited shunt and series fields and a separately excited control field. The shunt and series fields are so adjusted that with full load on the A.C. generator, no excitation is required in the control field. Thus the control field is used only to shift the exciter operating position on the straight line saturation curve.

The control circuit consists of a voltage measuring circuit and two parallel voltage comparison circuits each terminating in a rectifier bridge. The output of the three-phase line voltage rectifier bridge is compared to the output of the constant voltage transformer single-phase rectifier bridge and the difference is applied across the control field of the exciter as shown in Figure 6. Hence, any drop or rise in the A.C. generator terminal voltage will result in a voltage being applied to the control field in a boost or buck direction to restore the A.C. generator excitation and voltage.

Ward Leonard Electric Company "Statictor".

The Ward Leonard Electric Company "Statictor" type voltage regulation system when used with a Delco Products Division of General Motors Corporation shunt exciter makes up the only Navy type of rotary amplifier type voltage regulator where all exciter field excitation is supplied from the control circuit.

Essentially, the regulator excitation power circuit consists of a potential transformer, two current transformers shunted by a reactor and a rectifier whose output is connected to the exciter shunt field as shown in Figure 7. To obtain good voltage sensitivity for all load and service conditions, the three-phase respon-

sive voltage sensitive circuit is added to the excitation power circuit through a three-winding reactor.

The basic excitation power circuit may be considered as performing as follows:

(*a*) The potential transformer provides sufficient voltage to maintain the required excitation on the A.C. generator at no load.

(*b*) As load increases, the voltage drop across the current transformer increases to supply additional excitation power to the exciter field to maintain the A.C. generator voltage.

(*c*) For varying conditions of load and power factor this basic circuit will maintain A.C. generator voltage within a band of plus or minus 5 per cent. The required voltage sensitivity of plus or minus one per cent is obtained through the addition of the voltage sensitive circuit.

Conclusion.

In conclusion, it is desired to state that in spite of the relatively small physical size of a voltage regulator compared to the physical size of the generator which it controls, the voltage regulator plays an important and vital part in a ship's service power system and therefore must be given every attention in design and application. And while it may seem from the foregoing that great strides have been taken in the design and application of voltage regulators on Naval vessels, it is considered safe to assume that the next few years will see still greater improvements in the field of automatic voltage regulators.

SHIP'S SERVICE STORE EQUIPMENT DEVELOPED FOR U. S. NAVAL VESSELS.

By E. H. Honegger.*

†"A fighting man can find few luxuries on a destroyer cruising with the Tokyo-Bound Task Forces. One of the most important is ice cream, and our ice cream freezer is probably the most treasured piece of equipment we have."

The installation of ice cream making equipment aboard small naval vessels was a wartime development brought about by the realization that the supply of ice cream was a decided morale factor. This realization became apparent through the insistent and universal demands of the ships themselves, verified by an independent survey of forward area desires and confirmed by subsequent reports from the vessels receiving such equipment.

Prior to 1935 the installation of ice cream equipment was initiated by the commanding officer of the vessel and procured from the ship's own funds. Beginning in 1935 equipment was specified and supplied by the government for large combatant vessels and consisted of a soda fountain, an ice cream freezer, necessary refrigerating machinery and a 40 gallon capacity hardening cabinet with an additional 40 gallon cabinet permitted for aircraft carriers. This equipment allowed a maximum production, respectively, of 40 and 80 gallons of finished ice cream per day. The material so specified was standard commercial with few modifications for shipboard installation and required considerable field installation, labor and material.

With the advent of war, supplementary ice cream equipment was provided on the large combatant ships to keep abreast of the increase in vessels' complements. Certain additional classes covering large auxiliary vessels were also provided with similar initial equipment. Due to the unprecedented time at sea of the operating vessels, the desire to provide dairy products to diet and the

* Engineer Heat Transfer Section, Bureau of Ships, Washington, D. C.

† Quoted from a combat report received from a U. S. Destroyer operating in the Pacific Area.

realization of morale value of ice cream, authorization was issued in 1943 to equip smaller vessels including submarines. The quantity of material required for this program made practical the redesign of equipment more applicable for shipboard use. The accomplishment of this program covering the installation of ice cream making equipment on smaller vessels is reflected in Navy reports of monthly issues of prepared ice cream mix from a quantity of 387,000 pounds during the month of August 1943 to a peak issue of 5,525,000 pounds during the month of August 1945. This issue during the final month of the war represents an approximate production of 2,762,500 gallons of finished ice cream.

In designing and evaluating equipment required for the great quantity of surface vessels from 180 foot minecraft up through the largest carriers and battleships, certain factors were evident for consideration.

a. Adequate sanitary production of ice cream from equipment selected in order to provide sufficient quantity of finished product for ships increased wartime complement plus surplus for issue to smaller vessels within the operating area.

b. Flexibility of equipment to provide requirements of production with a minimum of sizes and models.

c. Standardization of component parts to enable quantity manufacture of identical equipment.

d. Simplification of installation to facilitate proper application with a minimum of field labor and material.

e. Satisfactory design and construction of equipment to provide trouble-free operation in extreme ambient temperatures and battle shock conditions.

The prepared Navy issue ice cream mix furnished to vessels is in powdered form and requires only the addition of water. In solution the liquid mix is equivalent to a fresh dairy product and requires a minimum of handling and a fast reduction in temperature to deter bacterial growth. The solution may be immediately inserted into the freezer for such accomplishment and the first step in the manufacture of the ice cream as indicated in the flow chart, Figure 1.

The liquid ice cream mix is thoroughly whipped and partially frozen in the batch freezer for approximately 15 minutes to a temperature nearing 25 degrees F, then whipped to a ribbony consistency. At this point the partially frozen ice cream is re-

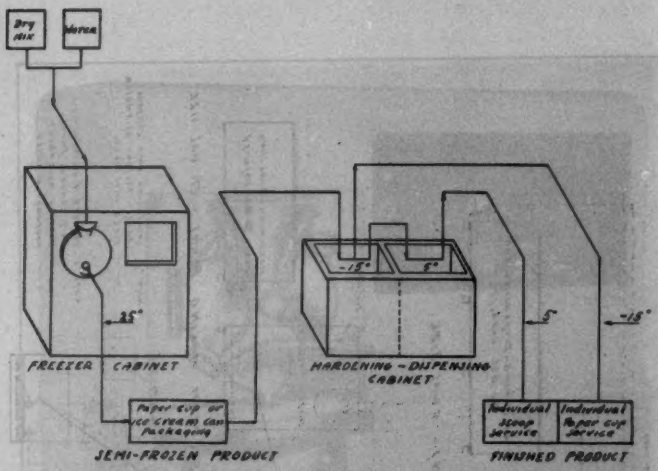


FIGURE 1.—ICE CREAM PRODUCTION FLOW CHART.

moved from the batch freezer, packaged and stored in a low-temperature cabinet for completion of the freezing process which normally takes from 12 to 18 hours when packaged in ice cream cans.

The ship's service store equipment being presently furnished to U. S. Navy surface vessels is outlined in Figure 2. A minimum of sizes are employed, units are completely factory assembled requiring only field inter-connections and further simplified by duplication of component parts where possible and by the use of one size condensing unit.

The condensing unit for freezer application is enclosed within the freezer cabinet with operating controls and gauges located on the control panel common to both freezer and condensing unit. Where the refrigeration unit is used solely for hardening cabinet or soda fountain application, the unit is separately located and provided with an individual control panel for bulkhead mounting. This adaptation permits interchangeability thus minimizing replacement parts and simplifying servicing and overhaul. The condensing unit is the air cooled type using Freon-12 as a refrigerant and consisting of compressor, condenser, receiver, motor, V-belt drive and accessories, factory assembled on a fabricated steel frame. Flexibility of operation for off peak load demand is

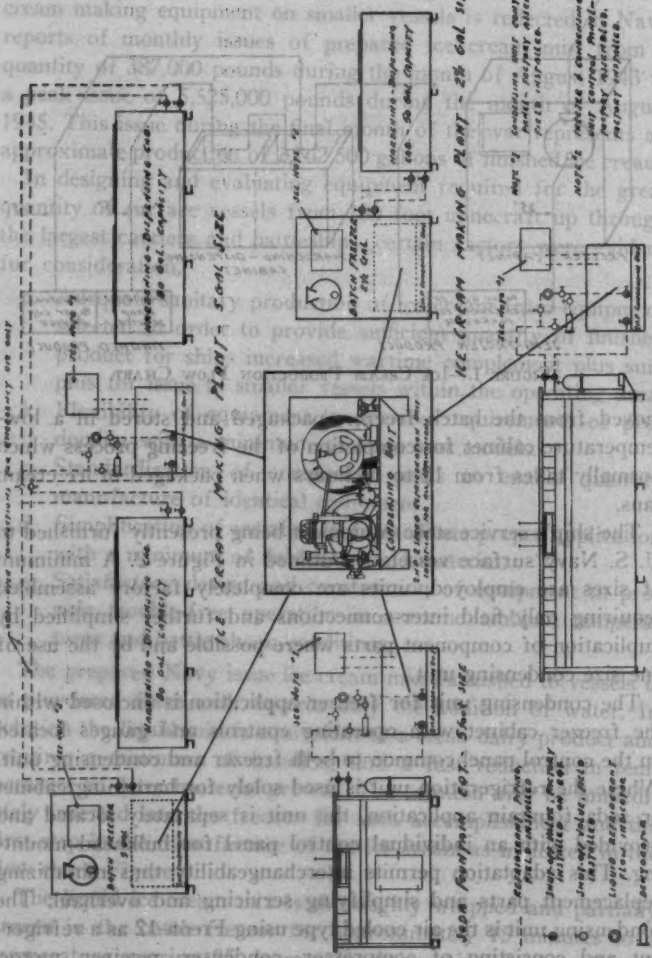

ICE CREAM MAKING PLANT - 5 GAL SIZE
ICE CREAM MAKING PLANT - 2½ GAL SIZE
SODA FOUNTAIN EQT. - 5 FT SIZE
SODA FOUNTAIN EQT. - 10 FT SIZE

FIGURE 2.—SCHEMATIC ARRANGEMENT OF VARIOUS SHIPS SERVICE STORE EQUIPMENT.

FIGURE 2.—SCHEMATIC ARRANGEMENT OF VARIOUS SHIPS SERVICE STORE EQUIPMENT.

FIGURE 3.—ICE CREAM BATCH FREEZER—FRONT VIEW.
(Courtesy General Electric Co. and Bastian Blessing Co.)

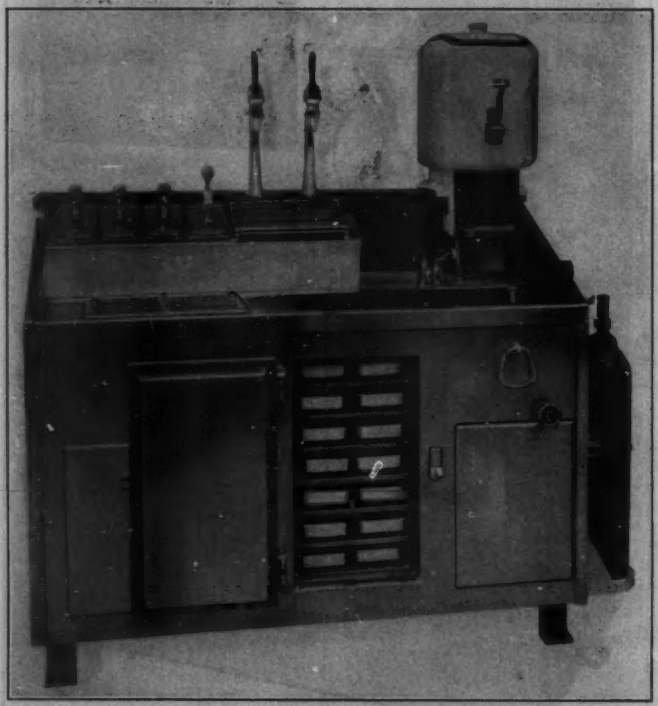
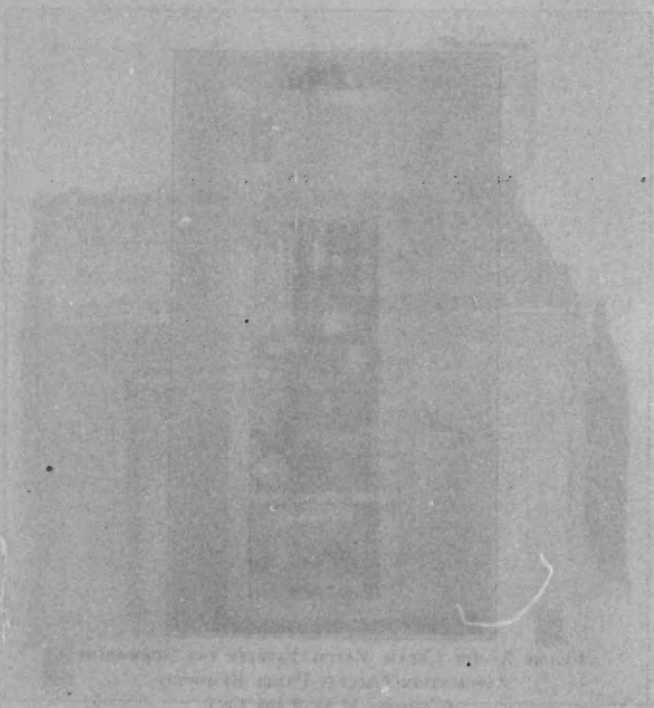


FIGURE 4.—SODA FOUNTAIN 5 FOOT SIZE (ICE CUBE DOOR OPEN).
(Courtesy Bastian-Blessing Co.)

FIGURE 7.—ICE CREAM BATCH FREEZER FOR SUBMARINE APPLICATION (ACCESS PANEL REMOVED).
(Courtesy F. W. Lang Co.)



effected by the use of two speed motor giving 50 per cent reduction in capacity. Condensers are provided with a condenser surface and air flow design to permit operation under 120 degrees F ambient temperature with an average condensing temperature not exceeding 135 degrees F.

The ice cream making equipment is provided in two sizes with daily capacity to make ice cream limited to the capacity of the hardening cabinets and time required to completely freeze the product. The 2½ gallon size consists of one self-contained 2½ gallon batch freezer including condensing unit, and one 50 gallon hardening-dispensing cabinet. The 5 gallon size consists of one self-contained 5 gallon freezer including condensing unit, two 80 gallon hardening-dispensing cabinets and one condensing unit for operation of both cabinets.

Batch freezer assembly. The ice cream batch freezer assembly is identical for both the 2½ gallon and 5 gallon units except for size of freezer cylinder and freezer motor. The unit as pictured by Figure 3 is completely factory assembled requiring only locating, securing and electrical connecting for operation. The assembly consists of condensing unit located in the base of the cabinet with the freezer assembly and control equipment located in the top section.

The freezing chamber receives refrigeration through copper tube surface tightly wound around a shell, bonded to it and externally insulated and protected. The shell provides a scrapping surface for the beater assembly which is V-belt driven by separate motor. The removable beater assembly located within the freezer shell, provides mixing action to enable rapid reduction of ice cream temperature and also by clutch action permits whipping of the semi-finished product.

Hardening Cabinets. Hardening cabinets are furnished in two sizes. The 50 gallon ice cream capacity cabinet consists of two sections of 30 gallons for hardening and 20 gallons for hardening or dispensing. The 80 gallon size is likewise partitioned to provide a 40 gallon section for hardening of the ice cream plus a 40 gallon section for hardening or dispensing. Each hardening cabinet is provided with separate refrigerant circuits and controls for automatically maintaining both sections of each cabinet at -15 degree F for complete utilization of the hardening capacity of the cabinet or for maintaining one section at -15 degree F

and the other section at 5 degrees F for a dispensing temperature in the event that ice cream cans are used. Where maximum capacity of equipment is not required on smaller vessels the available dispensing section is adaptable for frozen food storage with existing separate control action dependent on service use. Each cabinet is complete with controls, valves and piping, factory installed up to shut off valves and ready for field connection to condensing unit.

Packaging equipment. In order to maintain maximum production for daily demands of ice cream, specially designed packaging equipment was developed. This material, consisting of wire baskets and cup filling machines and cups, permits:

a. Faster freezing in hardening cabinet.
b. Full use of hardening equipment.
c. 100 per cent issue of ice cream manufactured.
d. Sanitary individual service.
e. A more palatable product.

Previously the custom was to package ice cream in 5 gallon cans which required 12 to 18 hours to harden dependent upon the application of the refrigerating equipment. With the use of paper cups this hardening period is reduced to 3 to 8 hours with the present plant since the surface of the cup has a greater ratio to the mass than a large container and since better circulation of cold air is possible around and thru the wire baskets.

When cans are used it is necessary to relocate the cans after hardening into a higher temperature compartment of approximately 5 degrees F to sufficiently soften the ice cream to allow scooping. This hand dipping process causes the loss of approximately 30 per cent of the volume of each can of ice cream due to compression caused by scooping thus forcing release of the whipped air within the ice cream which also results in a flat tasting product. While refrigerated space is used for dispensing, the hardening space is limited and production curtailed. The use of cups allows full use of the refrigerated storage capacity for hardening production and permits 100 per cent issue of ice cream produced. The ice cream served in cups is sanitary until consumed, and more palatable since it retains its smooth creamy texture. Cup service retards melting in high ambient temperatures due to the ability to serve the cream at hardening temperatures. This feature is especially desirous during mess service

where ice cream is located on a hot mess tray for a considerable time before consumption.

Soda Fountains. The soda fountain unit is supplemental to the ice cream machinery and is furnished only to the larger vessels and tenders where a minimum of equipment will serve a proportionately greater personnel. Each unit is self contained including carbonation equipment and requires only field installation and interconnection to utilities and condensing unit for operation. The 10 foot fountain, is issued where space is available, while the 5 foot fountain, a recent development, is provided where space is critical and to permit installation of multiple stations on the largest vessels where congestion of a single ships' service space would be encountered due to limitations of the area and excessive personnel being served.

The 10 foot fountain is an adaptation of commercially accepted arrangement with modification as to construction and with additional new features including specially designed carbonation equipment. This soda fountain is arranged with a 40 gallon capacity ice cream dispensing section maintained at 5 degrees F, a 40 degrees F miscellaneous storage section and refrigerated carbonated and fresh water system for beverage dispensing at approximatly 45 degrees F.

The 5 foot fountain illustrated in Figure 4 is provided with a 40 degrees F storage compartment, an ice making unit and an identical refrigerated carbonation system. The ice making equipment is a decided new function for a soda fountain and is provided to relieve the demand on ships store's ice making plant since ice is required for counter dispenser and individual iced drink service. The two units are similar to ice cream making equipment in construction with identical interchangeable parts provided where possible.

Soda fountains are normally supplied carbonated water by a separately located electrically operated paddle type agitator which admits CO_2 gas under pressure and pumps fresh water at tap temperature into a chamber where violent mixing takes place. This system is inefficient and results in a varying CO_2 content of the finished drink since high pressure CO_2 vapor is necessary for satisfactory absorption when mixed with fresh water of a varying high temperature as evident by absorption chart Figure 5.

While the accepted desirable concentration of CO_2 gas is

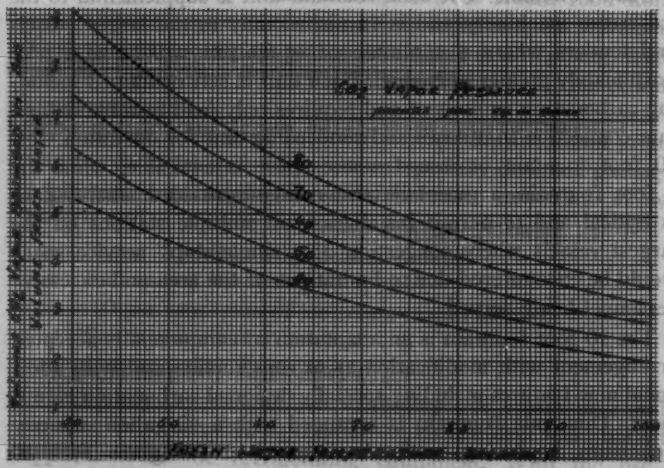


FIGURE 5.—RATE OF ABSORPTION OF CO_2 IN WATER AT VARYING PRESSURES AND TEMPERATURES.

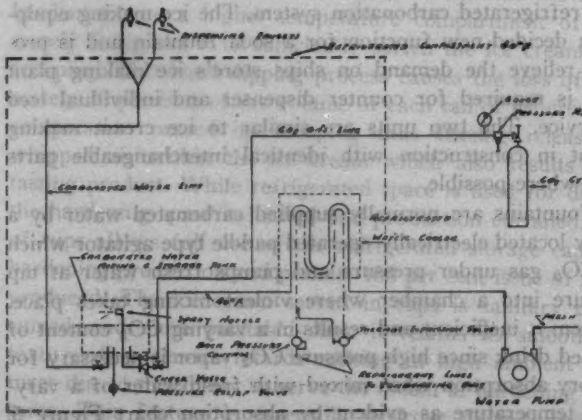


FIGURE 6.—CARBONATION EQUIPMENT—SCHEMATIC DIAGRAM.

between 3.0 and 4.0 volumes for a palatable drink, the absorption ratio must be kept sufficiently high to counteract decarbonation due to line loss, heat gain, pressure release and syrup mixing before the beverage is consumed. It is also indicated that a constant low temperature fresh water will allow lower CO_2 vapor pressure for equivalent absorption.

The carbonation system used on the Navy type soda fountains is shown by the schematic carbonator diagram Figure 6. The fresh water is pumped into the carbonator tank against CO_2 gas pressure with a maintained constant volume within the limits of the electrical float switch operation. The fresh water enters a refrigerated cooler which reduces and automatically maintains the leaving water at a temperature of 40 degrees F for admission to the carbonator tank which is located within the 40 degrees F refrigerated section of the fountain. The fresh water is sprayed thru an orifice within the tank where absorption with CO_2 gas readily results at the reduced temperature.

Two 15 pound capacity CO_2 cylinders completely factory connected are mounted on the end of the soda fountain to minimize piping and simplify field installation. One cylinder is used for stand-by service while the other is connected for operation. Provision is made for recharging the cylinders from existing ships supply of CO_2, thus eliminating the need for surplus soda fountain CO_2 containers with the resultant traffic of such cylinders to and from shore based recharging stations.

Control. The automatic operation of each condensing unit is accomplished by means of low pressure switch in the control circuit of the compressor motor which is actuated by pressure changes within the suction refrigerant line. The admittance of refrigerant to each cooling circuit except soda fountain water cooler is controlled by an electrical solenoid valve.

The solenoid valve in the freezer circuit is manually operated by a toggle switch located on the control panel to permit the operator to control ice cream production. Other solenoid valve applications are automatically controlled by thermostat operation. The temperature of the water cooler used in the soda fountain is controlled by a back pressure regulator to maintain a constant cooler temperature to prevent the possibility of freezing the water within the cooler.

Installation. The equipment is constructed to provide complete

factory assembly where practical in order to reduce necessary field labor and material. After the equipment is located aboard ship the car channels supporting the assembly are secured to the deck and refrigeration liquid and suction copper tubing is field connected between the shut-off valves provided on each unit of equipment where interconnection is necessary. The installed lines can then be purged of air by admitting a quantity of Freon-12 under pressure from the unit. Upon closing the circuit and connecting necessary electrical power connections the equipment is ready for operation. In addition to the refrigeration and electrical interconnections, the soda fountain units require water and drain connection to the terminal fittings provided and accessible from the end of the fountain enclosure.

Submarine Equipment. Complementary to the equipment being furnished to surface vessels, a specially designed compact unit illustrated by Figure 7 was developed for submarine application. The unit is completely self-contained requiring electrical connection with provision being made for removal of the finned condenser to permit lowering the assembly thru the vessel hatch. The freezer unit is a vertical type with a capacity of 3 gallons of finished ice cream. After the ice cream mix is semi-frozen and whipped, the beater blade assembly is removed and the hardening process continued for approximately three hours until the cream approximates 5 degrees F. Under this method the ice cream is served directly by scooping from the mixing chamber.

The air cooled condensing unit using Freon-12 as a refrigerant is a special assembly adapted to conform to the limitation of space with the compressor, condenser, receiver, motor and drive mounted on supports integral with the freezer enclosure frame.

The construction, control and operation of the unit is similar to that used on surface vessels.

NOTES.

INDEX TO NOTES.

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—The Military Engineer, Feb., 1946.

THE FUTURE OF THE BATTLESHIP.
—Journal of the Royal United Service Institution, Aug., 1945.

DIESEL ENGINE BEARINGS.
—British Motor Ship, Oct., 1945.

SOME SIMPLIFIED HEAT TRANSFER DATA.
—Journal of the Institute of Fuel, Dec., 1945.

SHIPBOARD CORROSION PROBLEMS.
—Pacific Marine Review, Jan., 1946.

SOME FUNDAMENTALS IN ALL-WELDED SHIP CONSTRUCTION.
—Welding Journal, Oct., 1945.

SECOND INTERIM REPORT OF THE BOARD TO INVESTIGATE THE DESIGN AND METHODS OF CONSTRUCTION OF WELDED STEEL MERCHANT VESSELS.
—Exhibit IV—Survey of Research Projects, April, 1945.

RADAR COUNTERMEASURES.
—Product Engineering, Jan., 1946.

THE U. S. NAVY'S FLOATING DRY DOCKS.

This complete description of the various types of floating dry docks, which aided the Navy in carrying on its global war, was presented by Commander Werner Ammann (CEC) U.S.N.R., before the Louisiana Post of The Society of American Military Engineers and the Louisiana Engineering Society. It is reprinted from the February 1946 issue of "The Military Engineer."

The Bureau of Yards and Docks, since its inception in 1842 by Act of Congress, has been charged with the design, construction, operation, and maintenance of the U. S. Navy's shore establishments. One of the Bureau's major phases has been, and is, the construction and maintenance of facilities for docking of ships. These facilities include marine railways, graving dry docks, and floating dry docks.

During peacetime, docking facilities are required mainly for routine underwater maintenance of ships, such as cleaning, painting, checking shafts and propellers, sea chests and intakes, with occasional underwater damage repair. During World War II the tremendous increase in number of ships, not only in the Navy but also in the Army and the Merchant Fleet, has been evident. In order to be prepared for the prompt repair of war-damaged ships, the rate of increase of docking facilities had to be on an even greater scale. Time required in dock for scraping and painting a battleship's bottom is only two days, whereas repair of moderate hull damage runs into weeks or months. The then Chief of the Bureau of Yards and Docks, Vice Admiral Moreell, foresaw, even long before our entry into the war, this huge increasingly urgent need of docking facilities and he took action. Plans were prepared, funds allocated, contracts awarded, and construction started on additional dry-docking facilities. Emphasis at first was placed on facilities in the United States proper, particularly on large battleship size graving dry docks at the various Navy Yards, such as New York, Philadelphia, Norfolk, Mare Island, and Pearl Harbor. One large graving dock at Pearl Harbor was completed only two days before the Japanese attack and, fortunately, was not damaged in that raid, so the part that it played in rehabilitating the damaged battleships there can well be realized.

In addition to graving docks, floating dry docks were constructed for use at commercial yards, using Navy funds. These floating docks gave flexibility to the program. If, as it later developed, more docking facilities were needed on the west coast or in the Pacific, these floating docks could be readily moved to new locations to meet the changing circumstances.

After our entry into the war, the needs began to change. Additional mobile facilities had to be provided for docking all types of ships, from Motor Torpedo boats to the big *Iowa* class battleships then being constructed. Also, the Navy Department was assigned the task of repairing and maintaining the ships of the Army and Merchant Marine in addition to those of the Navy. This meant that an unprecedented increase in docking facilities had to be provided, not only within the continental limits of the United States, but at advanced bases. Emphasis was, therefore, shifted to, and construction further accelerated on the floating dry dock program. In addition to the advantage of mobility, the floating dry dock as compared with the graving dock can be constructed in less time and can be operated at locations where foundation conditions preclude construction of a graving dock. On the other hand, maintenance costs of floating docks are greater, and their expected length of life less than those of graving docks.

Basic Principles and Types of Floating Docks.

For those not familiar with a floating dry dock, a brief description of its general principles is presented. Basically, it consists of a pontoon into which water is admitted for submergence under a ship. The water is then pumped out, its buoyancy lifting the ship clear of the water. Sidewalls are required to prevent the pontoon from sinking out of control once it is completely submerged. The most usual design today is a "U" or trough-shaped dock.

Floating dry docks are not new structures. A number of them were constructed and placed in operation in Germany, Great Britain, and other countries in the last century. The U. S. Navy began using them about 1850, but they never played the significant or strategic role that they did during the last war. In that respect the floating dry dock can be considered one of the new weapons of World War II since it enabled our fleet to be maintained and repaired at mobile advance bases close to the scene of action.

There are two general classifications of dry docks built by the Bureau of Yards and Docks: first, the non-military type, for home use, constructed as simply as possible and depending for power, compressed air, and other facilities on shore supply; second, the military type, for overseas use, having self-contained power plant, and being equipped with various shops, officer's and crew's quarters, messing facilities, storage, reefer and office spaces, antiaircraft guns, sick bay and other facilities—in fact, a combination of floating ship and Navy Yard.

There are many types and sizes of floating docks, with Navy designations almost as numerous as those of Landing Crafts.

The *AFD, Auxiliary Floating Dock*, is a small, single-piece steel "U" dock with lifting capacity of 1000 to 1900 long tons, generally constructed as a military type. It is designed for docking mine, patrol, and smaller landing craft and destroyer escorts. Quonset huts are used as crew's quarters while under way and at location will be placed ashore or onto barges alongside and utilized as shops and crew's living facilities. The pontoon is constructed with faired bow and stern to facilitate towing. It is a mobile type dock since it can be placed in operation shortly after arrival at its base. Its power plant, pumps, and other operating machinery are located in the upper portion of the wing walls in the so-called safety compartments. The dock's ballast tanks are in the lower portion of the wing walls and in the pontoon. The primary function of the safety compartments is to prevent complete sinkage of the dock when the dock's ballast tanks are completely flooded.

The *ARD, Auxiliary Repair Dock*, is a single-piece steel dock with a lifting capacity of 4000 tons. It has a ship-like hull with closed bow and stern gate to form a closed docking basin. It docks destroyers, submarines, and LST's (Figure 1). The ARD is a very mobile type dock and practically all of them have been constructed as military docks. Due to its mobility and general usefulness in docking all ships up to and including destroyers, it is usually the first type to reach advanced bases, and consequently it has had its share of bombing and strafing. On its initial outward trip it is used as a freight and small ship carrier. The dock is equipped with two 10-ton revolving gantry cranes for servicing the dock and ship in dock. Experiments have been made with the ARD for performing dockings at sea. Ordinarily a floating dry dock is designed for operation in a protected harbor where seas and ground swells are small. At sea the roll and pitch of the ship are not the same as those of the dock and the problem is to dampen any relative motion between them at the time the ship's keel is ready to land on the dock's blocking. Experiments have been made with large hydraulic shock-absorbing keel and bilge blocks. By their use successful trial dockings at sea have been performed, but further trials and improvements along these lines are contemplated. This will open up a new field for the floating dry dock where it will travel with the auxiliary service fleet or even with the battle fleet for on-the-spot emergency aid.

The *ARDC, Auxiliary Repair Dock Concrete*, is a 2800-ton capacity single-piece concrete dock designed for both home and overseas use. (Figure 2.) It is similar in outline, though larger than the AFD steel docks. Its hull walls and bulkheads are made of approximately 6-inch-thick normal aggregate concrete. It is less efficient than a steel or timber dock as regards its lifting capacity ratio to its dead weight. However, it was designed to save critical steel, and has proven a successful small dock, requiring a minimum of hull maintenance work, and able to stand the pounding and stresses of heavy seas during towing.

The *YFD, Yard Floating Dock*, includes a wide variety of types, as follows:

a. The 1000-ton to 5000-ton single-piece timber docks (Figure 3).

b. The 6000 to 20,000-ton sectional timber docks. This brings up the self-docking feature in floating dry docks, that is, a dock so designed that parts or sections of it can be docked in the remaining portion of the dock. The sections of the sectional timber docks are connected to each other by locking logs for transferring shear only, since they give practically no overall bending strength to the dock. For docking of a section, locking logs are removed, the section turned 90 degrees and brought into the submerged portion of the remainder of the dock.

c. The 16,000-ton special Rennie type dock, "U" shaped, with steel wing walls and timber pontoons bolt-connected to the wing walls. It has the advantage of longitudinal strength and ease in self-docking. For self-docking a pontoon, the connections to wing wall are removed, the pontoon lowered, slipped out endwise and brought into submerged remainder of dock.

d. The 14,000 to 18,000-ton three-sectional steel docks for docking light cruisers, transports, cargo ships, tankers, hospital and similar type ships. It is a trough-shaped dock with long center section and two short end sections. The end sections are capable of docking the center section and in turn can themselves be docked in the center section (Figure 4). For towing to forward areas the end sections are cradled and secured within the center section. A new feature is incorporated in this dock, a so-called buoyancy compartment in the center of the pontoon, directly under the keel blocks. Its purpose is to provide greatest buoyant force at the location of greatest ship load, thus producing lesser transverse bending moment in pontoon and lesser differential water pressure on wing wall plating and framing.

Finally, the *ABSD's*, the *Advanced Base Sectional Docks* in two sizes; a ten-section steel dock with a total lifting capacity of 100,000 tons for docking of battleships or large liners like the *Queen Mary* or the *Queen Elizabeth*, and a seven-section steel dock with a total lifting capacity of 56,000 tons for docking heavy cruisers, including the new *Alaska* type battle cruisers, aircraft carriers, and the smaller, older class battleships. Each section of these sectional docks is complete in itself as far as electric power, salt water, compressed air, crew's messing and bunking, and other facilities are concerned, so that it can be towed to an advanced base as an independent unit. Furthermore, the sections being practically alike, are interchangeable. Thus, in case of loss or serious damage to any sections, the dock can operate with less than the requisite number of sections. The pontoon ends of each section are faired for ease in towing. The wing walls are built in, or jacked down to the lowered position to give greater stability and lesser wind area presentment during tow. The towing vessel is either a seagoing tug or a Liberty ship. If the Liberty ship does the towing, it, at the same time, transports materials and equipment that will be used by the dock in ship repair work.

Construction.

The various sections are constructed in yards on both the Pacific and Gulf Coasts. Some sections have been built in the Pittsburgh area, towed down the Ohio and Mississippi Rivers to the Gulf of Mexico, and from there been taken via the Panama Canal to advanced bases in the Pacific area. The sections of any one dock are not usually built in the same yard. For instance, the ten sections that were first completed were planned for making up the complete ABSD-1. This dispersal of construction resulted in completion of the first dock in much shorter time.

The cost of the sectional docks runs in the neighborhood of about $3,000,000 per section complete, or a total of about $30,000,000 for the battleship dock. But, if it can save or help save a $100,000,000 ship, not to mention repairing and maintaining hundreds of ships close to the fighting front, getting them back into action weeks and months sooner than if they had to make a trip back to Pearl Harbor or the West Coast, thus materially shortening the war

FIGURE 1.—AN ARD WITH SUBMARINE IN DOCK BASIN.

FIGURE 2.—AN ARDC UNDER TOW. NOTE THE CRANES ON WING WALLS.

FIGURE 3.—A 1,000-TON SINGLE-PIECE TIMBER DOCK IN FOREGROUND. NOTE SINGLE SECTION OF A 20,000-TON SECTIONAL TIMBER DOCK IN LEFT BACKGROUND, READY FOR LAUNCHING.

FIGURE 4.—CENTER SECTION OF AN 18,000-TON THREE-SECTIONAL STEEL DOCK BEING DOCKED BY THE END SECTIONS.

FIGURE 5.—WING WALL RAISING OPERATION ON SECTION OF BATTLESHIP DOCK.

FIGURE 6.—CRANE BEING TRANSFERRED FROM PONTOON DECK OF ONE SECTION TO WING WALL DECK OF PARTIALLY ASSEMBLED SECTIONAL DOCK.

the cost is justified. Furthermore, they will all have peacetime usefulness in docking merchant and passenger ships. The Bureau's total investment in floating dry docks is about $450,000,000. Great credit is due to the designers of these docks. The Bureau laid down the basic design requirements for all types of docks and, further, it completely designed some types. The consulting engineering firm of F. R. Harris, Inc., at New York was the designer of the ABSD's, the three-sectional steel YFD docks, timber docks, and other types. Great credit is also due the contractors and their workmen, to their know-how and will to push to completion in the face of difficulties. One of the stipulations laid down for this dry dock construction program was that it must not interfere with the Navy's shipbuilding program. For that reason contractors like the Chicago Bridge and Iron Company were chosen. Construction sites were chosen, like Morgan City, Louisiana, in order to utilize labor not otherwise engaged in vital shipbuilding or other war industries. This meant training of contractors and men who had not previously been engaged in shipbuilding, but they soon learned and admirably met the challenge.

Towing, Assembling, and Operating.

Since I was directly attached to the U.S.S. ABSD-1, the first of the large sectional battleship docks, during its towing, assembling, and operation period for about two years, I shall here describe in narrative form and in greater detail the work involved in assembling the dock and mention a few of the incidents that occurred during that time.

After completion of construction, the floating dry docks that are destined for forward areas, are turned over to the fleet as commissioned ships of the Navy. They are commanded by a Naval Line Officer and operated by officers and enlisted personnel of the Navy. I was assigned to the U.S.S. ABSD-1 as Maintenance and Dock Control officer. During the early days of getting the ABSD-1 ready to put to sea, the following were some of the jobs that had to be performed by the officers then assigned to the ABSD-1:

a. Study the plans and specifications at the designer's office and make recommendations for any necessary changes that could be performed without delaying construction.

b. Make list of, and check on procurement of auxiliary equipment, tools, and materials required for outfitting, assembling, and operation of the dock. This included such items as binoculars, weld rods, barges, tugs, bolts, nuts, crawler cranes, and thousands of other items too numerous to mention.

c. Organize the ship's officers and crew into departments and divisions. The enlisted men were procured from the Floating Dry Dock Training Center at Tiburon, near San Francisco. This training center was set up for the purpose of training floating dry dock personnel. However, further instructions and training were given them in connection with their particular duties on the ABSD-1. The battleship sectional docks have a complement of about 30 officers and 750 enlisted men.

d. Make submergence, wing wall raising and machinery, and equipment tests.

In June of 1943, I was sent to Morgan City, Louisiana, to take charge of the two sections of the ABSD-1 leaving from there. The other eight sections were to proceed separately from San Francisco. Then came our final frantic efforts to complete construction of the sections, stow all necessary gear and equipment, secure them for sailing, provision them for three months at sea and make final convoy, towing, and signaling arrangements.

One of our first worries was getting over the mud flats of the lower Atchafalaya River to deep water in the Gulf of Mexico. The channel at its narrowest and shallowest section was only 100 feet wide by 8 feet deep at mean low water. Since our sections drew more water than that, it was necessary to get over the shallow section quickly at high tide. Even so, the small inland tugs that towed us to the Gulf churned up mud continually and got partially stuck several times. At deep water in the Gulf we were met by the ocean-going

Section to Wing Wall Deck of Partially Assembled Sectional Dock.

tugs and escort vessels. Our new tow was made up and we got under way on our long trip.

Upon arrival at Panama our queer looking ship apparently caused considerable speculation. We received a signal from one of the patrol crafts asking "What is it?" to which we replied, "New secret weapon."

In the Pacific our trip was fortunately practically without incident. For a period of thirty days we saw neither land, plane nor ship other than those in our convoy, which is believed to be quite a record in these days of fast travel. Some storms, though none of great severity, were encountered. In moderately heavy seas we rolled about 30 degrees, and since the sections are flat bottomed and very stable the roll was stiff and quite rapid.

Our final destination proved to be one of those beautiful coral lagoons in the South Pacific that one reads about. The waters in the bay were a deep blue and clear enough so one could see bottom in 40 to 50 feet. The waters contained thousands of multi-colored tropical fishes and coral formations, and the bay was surrounded by sandy beaches and cocoanut groves. However, this beauty palled on us the longer we had to stay there.

Our first job out there was to remove all topside equipment and make other preparations for wing wall raising. The wing walls were then raised, section by section, into the upright position by means of two long steel jacking columns with 500-ton hydraulic jacks at their base. Figure 5 shows details of this jacking equipment. Raising was accomplished by jacking one column the length of the distance between pin holes, lowering the second column, pinning off second column at its connection to the wing wall, and then jacking with second column. This cycle was continued until the center of gravity of the wing wall passed over the base hinge. From there on the wing wall was moved into its upright position by a second set of smaller jacks engaging a tension harness. The wing wall was then secured to the pontoon by 2-inch diameter bolts spaced at 12-inch centers around the periphery of the wing wall.

After the first section's wing walls were raised, it was moved to its final location and secured to the mooring anchors and chains. Thereafter, as the wing walls on each subsequent section were raised, it was brought alongside the assembly, flooded or pumped to correct alignment and splices made. The connections between sections consist of 1¼-inch splice plates engaging 2-inch keeper plates at the tops and bottoms of the wing walls. These keeper plates can be seen in Figure 6. The splice plates were erected by means of hand-operated 1-ton stiff-leg cranes especially provided for this purpose. The splices were first bolted to kill any motion between sections and then fillet welded to the keeper plates There are no structural connections between adjacent pontoons, thus the sectional docks in their assembled condition become a Rennie type dock. The connections between the wing walls were designed to give the dock a total moment strength of 500,000 foot tons and a total inter-section shear strength of 8000 tons. This design moment strength was chosen at about 25 per cent of the moment strength of the largest battleships to be docked. At first it was considered necessary to design these docks for a moment strength practically equal to that of the largest ships, on the basis of having to dock such ships in a battle-damaged condition, where they had practically lost their moment strength. This would have meant an unwieldy and very costly wing wall and wing wall connection design. In view of the above and the urgent necessity of completing the docks in the least possible time, and on the basis of proper dock flooding and pumping and proper deflection control during these operations, the lesser moment strength design was decided upon. In actual operation the docks proved to be comparatively flexible, but under proper operation and control the overall deflection could readily be kept within plus or minus 3 inches in the length of the dock (827 feet). This is well within the general requirement of not deflecting a ship more than 1 inch per 100 feet of length. A 3-inch deflection in the length of the dock produces an extreme fibre stress in the wing wall splices of about 3500 pounds per square inch; in other words, an overall deflection of 18 inches would not produce stresses beyond the working allowable. If necessary to dock a ship

with such battle-damage as to be almost lacking in longitudinal strength at point of damage, the overall deflection of the dock could be kept within plus or minus 1 inch by slower than normal operation of the dock. The sectional dock as designed has, therefore, proven itself more than adequate to meet all strength, stability, and stiffness requirements.

As assembly of the dock proceeded, additional moorings were laid. The completed dock was moored with thirty-two 15-ton anchors and 3-inch cast steel chain. It was moored in approximately 30 fathoms of water with its longitudinal axis in the direction of the prevailing wind.

The crane transfer operation incident to dock assembling was interesting and fraught with some hazard. During sailing the two cranes were secured on the pontoon deck of two of the sections. Upon arrival at location these cranes were operated while in this position on the pontoon deck of their respective sections, thus greatly aiding in all the multitudinous weight-handling jobs. After several sections were assembled with their wing walls in the upright position the cranes were transferred to the wing wall decks. This was accomplished by the following steps: (a) Flooding the partial assembly until its wing walls reached same elevation as pontoon of crane sections, (b) bringing crane section alongside submerged assembly and securing it there by special prestressed cables, (c) installing special rail links across gap, (d) transferring crane using its own travel power, (e) disconnecting previous crane section and, finally, (f) pumping up partial assembly.

Total time to assemble our dock was about 3 months. Later docks, due to experience attained with the first one, took from 2 to 2¼ months.

In these sectional docks there is a buoyancy compartment in the center of the pontoon that has the same purpose as the buoyancy compartment previously described in the three-piece steel YFD type dock. However, in the sectional docks this space is utilized for fuel oil and water storage, for housing the dock's machinery including diesel engines, generators, pumps, boilers, evaporators, and auxiliary equipment, and for the crew's living and messing quarters. Normally, when the dock is in the up position, access to the buoyancy compartment is through hatches and scuttles on the pontoon deck. During submergence these hatches and scuttles are closed and access to the buoyancy compartment spaces from the wing wall deck is had down vertical circular stairways within the wing walls and through passageways within the pontoons. The safety compartment spaces in the tops of the wing walls are utilized for the ship's offices, officers' wardroom and quarters, sick bay, crew's recreation facilities, refrigeration and storage compartments, machine, shipfitter, sheet metal and carpenter shops, and other facilities. Due to the fact that the wing walls were in the down position during sailing, practically all of the facilities in the wing wall spaces had to be constructed and installed by our ship's force. This took a long while since the work was made secondary to ship repair work.

As previously mentioned the dock is comparatively flexible, and since extremely heavy ship loads and buoyant forces had to be dealt with, measures had to be taken to prevent excessive dock distortions during operation, that might be injurious to either the dock or the ship in dock. Fundamentally, the problem is simply to pump each section, such that the upward buoyant force of that section equals the portion of the ship load on the section, during all stages of pumping. If that is done there will be no shear or moment transfer between sections of the dock, or parts of the ship. Previous to docking a ship, pumping calculations are made based on the principles stated above. However, as a secondary check to insure prevention of large deflections, particularly since at first the tank water level indicating system was not completely reliable, a deflection control system was installed on the dock. Vertical and horizontal sighting battens or targets were installed on each section of both wing walls, and an engineer's level was set up on the top of both wing walls at the head of the dock. By setting the cross hairs of the level on the target at the after end of the dock, vertical and horizontal deflections of the intermediate sections were continuously read through the telescope of the level. Sensitive list and trim indicators in the control house gave

information as to changes in list and trim during pumping. Two cruisers or two cargo ships whose combined overall length is so great as to prevent them from being docked on the longitudinal centerline of the dock, could be docked by offsetting the forward ship to port and the after ship to starboard, or vice versa. This, however, required differential pumping between port and starboard sides of the dock. Since the dock had very little strength for resisting torsion about its longitudinal axis, a system for detecting any undue torsion had to be developed. This was done by installing a list indicator on the after end of the dock, and by taking simultaneous readings on forward and after list indicators; any difference between the two gave a measure of the overall dock torsion. Intermediate torsion was detected by readings on the horizontal and vertical deflection battens. Offset docking of two cruisers and other ship combinations has been successfully performed, by use of the above control system.

Self-docking of any of the pontoons of the large steel sectional docks can be accomplished by removing the 2-inch bolts connecting the pontoon to the wing walls, lowering the pontoon several feet for clearance, moving the pontoon out end-wise, and finally docking in the remaining portion of the dock. The self-docking feature of floating dry docks is, of course, more important in the larger type docks, since the smaller docks can be docked in the larger floating or graving docks for underwater repairs or maintenance. During the present war all the docks have been so busy performing their primary function, that it has not been possible to do any self-docking other than for emergency cases. However, for later peacetime maintenance the self-docking feature for larger docks will be of great importance.

Conclusion.

In conclusion I would also like to acknowledge the deserving credit due the enlisted men of the Navy who were attached to the dry docks, for their part in the assembling and operation of these docks. Due to their persevering and enthusiastic work at all times of day or night in the face of adverse weather and other conditions, they made it possible to get battle-damaged ships back into fighting condition quickly. Thus, the all important part played by these dry docks in World War II was due to the co-operative efforts of their designers, constructors, and operators.

THE FUTURE OF THE BATTLESHIP.

This short article from the "Journal of the Royal United Service Institution" was prepared by Lt. Comdr. D. R. Webster, R.N., furnishes food for thought on the design of future battleships.

In past wars, and indeed at the beginning of the present war, the hitting power which formed the indispensable basis of sea-power was provided by the big guns of the battleship. These units were the most valuable part of the Navy and the final arbiters of action between fleets; all other units were auxiliary to them, and designed either to assist our battleships to come to grips with the enemy or to frustrate or injure those of the enemy.

The importation of the air arm into naval warfare in general, and more particularly into naval actions, would seem to call for reconsideration of both the role and design of the battleship. Judging from reports of such actions in the Pacific, they have been fought and won without any contact whatever between the ships of the opposing fleets. On both sides the air arm supplied the hitting power which in earlier wars would have been provided by the guns of the battleship.

The aircraft carrier, as the base from which this striking power operates, has thus developed from being an auxiliary to the battleship into the chief instrument of destruction, and as a logical consequence the most valuable unit of the fleet. The protection of these valuable ships now becomes of first importance, more especially since by reason of their role and design they are themselves very vulnerable. Obviously, since close contact with the enemy

surface forces is unlikely to take place, protection from the chief menace—the air, is the problem. How is this to be achieved?

At present the only really effective means of protecting a ship from air attack are fighter aircraft and gun-fire, including rocket-guns. The carriers themselves can, it may be aruged, supply both. They can, but interception of every enemy aircraft and its destruction before it has made its attack cannot be relied on, while the protection afforded by the guns is limited. The limitations are two-fold, first because no carrier can carry enough guns, secondly because for protection against high-level bombing the close vicinity of the target itself is the least suitable site for the guns designed to prevent the attack. Gun attack on the high-level bomber, to be effective, must be made beyond the point of bomb-release, before and during the run-up to the target. In other words the guns need to be from four to twenty miles from the target which they are protecting. It follows that what is required is a number of floating A.A. batteries.

There are already in existence A.A. light cruisers which act as protection to the larger units, but the number of guns which they can carry is not great, and they suffer from the disadvantage of being themselves very vulnerable even to a near-miss. What of the battleship redesigned as a floating A.A. fort? With the removal of its big guns a considerable space and a very great tonnage would become available for increased heavy A.A. armament and increased deck armor. Such a ship would have guns enough, not only for her own close-range protection, but also to be able to break up a formation of high-level bombers on the run-up to their target. The protection afforded would be infinitely superior to anything now available, while this A.A. fort would be as little vulnerable as is the present battleship.

It may be asked why stress is laid on high-level bombing and the consequent suggested need for increased heavy A.A. armament. It will be augued that nearly all the ships sunk by naval aircraft have been sunk by dive, or torpedo-bombers, and that, since battleships now carry enough short range weapons to cope with such attacks on almost any scale, there can be no reason for removing the big guns, which may come in useful, and for fitting more heavy A.A. guns. In the writer's view losses to the Japanese in dive, and torpedo bombing attacks have recently been so severe that they, and other navies also, will be compelled to revert to high-level bombing. That this will demand, heavier bombs carried by larger aircraft flying from bigger carriers is true, but it seems an inescapably logical development, unless some entirely new means of sinking armored ships can be devised.

The tactical need noted in paragraph 4 for heavy A.A. guns to be located or sited at a considerable distance from the target which they are to defend introduces a dilemma. Either the floating batteries must be provided in large numbers or else they must be brought in nearer to the target than is desirable. If this is not done, then there will be considerable gaps in the gun defense through which enemy aircraft can approach. Since it is unlikely that battleships of the 35,000–45,000-ton classes can ever be provided in sufficient numbers, it thus becomes necessary to consider the future design of the battleship not only as regards type of armament but also as regard size. The requirement can best be put in the form of a question, "what is the lowest tonnage required to provide close-range A.A. weapons on the same scale as carried by existing 45,000-ton battleships plus long-range A.A. guns 100 per cent in excess of those now carried while retaining existing speed and armor protection?" To the writer it seems probable that the answer will be found to lie between 24,000 and 30,000 tons.

Two possible objections to the proposed design of battleship for this role come to mind. First there is the possibility that a fleet at sea in really heavy weather and with no big-gun battleships might be met by an enemy *with* big-gun battleships, in which case it would stand little chance of making a successful fight. Is this such a likely contingency that it is vital to retain the big-gun battleship in its present form? Is it not probable that developments in the size of aircraft carriers, and the consequent increase both in the size of the flight-deck and in the steadiness of these ships in a sea-way, will so limit

the occasions on which take-off and landing-on are quite impossible as to make such a contingency extremely remote? Already, experience with escort carriers in the Atlantic has shown that with skill and patience it is possible to fly-off and land-on in weather which would formerly have been thought so bad as to make it impossible to do either.

The second objection is that without the big-gun battleship the Army would be deprived of one of the most vital forms of naval co-operation before, during and after an assault landing on a defended coast. This would be the case unless the place of the battleship were taken by some other class of ship designed specifically for such a role, as is the monitor.

This short paper is only an attempt to focus and crystallize thought on the subject. Since a mistake in a matter of such moment would be well-nigh a national disaster, conservatism becomes almost a virtue. Nevertheless the writer feels that the considerations outlined above merit examination. This in his view, is the more urgent since the conclusion of the war will almost inevitably, as in the past, lead to financial starvation and doctrinal stagnation in the Naval Service.

The questions to be answered are:

(1) Is this statement of the new primary role of the battleship a correct one?

(2) Does the design suggested follow logically from this role?

(3) If so, are the objections to it sufficiently weighty to qualify or limit its adoption in practice?

DIESEL ENGINE BEARINGS.

This abstract of a paper by L. M. Tichvinsky, read before the Oil and Gas Power Division of the American Society of Mechanical Engineers, is reproduced from the October 1945 issue of the "British Motor Ship."

The object of this paper is to describe common Diesel-engine bearing operation and failures, to set forth methods of progressive inspection of bearing failures, and to indicate rational bearing-maintenance methods.

Operation of Diesel-engine Bearings.

Maximum Diesel-engine bearing pressures are quite high because of high cyclic loads. The operations of piston pin, connecting rod and main bearings of a Diesel engine differ and depend on the type and magnitude of loading.

Piston-pin Bearings.—Maximum pressures are very high and might be of the order of 6000 pounds per square inch. They are due to large peak forces in conjunction with comparatively small bearing diameters. The loading is due primarily to gas and inertia forces. Because of a swinging or rocking motion of the connecting rod, the load acts over a small arc of the bearing circumference, spanning approximately plus or minus 15 degrees. The lubricating-oil temperature is rather high, because it is usually supplied through the main and connecting-rod bearings successively. Piston-pin surfaces are very hard, approximately 60 Rockwell C hardness at 150-Kg. load. Their surfaces, often chromium-plated, are very smooth, below 10 micro-inches. The piston-pin bearings are designed with small clearances, and successful operation depends greatly upon the damping properties of the lubricating oil.

Connecting-rod Bearings.—Maximum pressures in this case are also very high and may reach values of approximately 3000 pounds per square inch. The loading of the connecting-rod bearings is due to gas, inertia, and centrifugal forces. The upper shell supports most of the load in a two-cycle Diesel engine, while in a four-cycle Diesel engine both the upper and the lower bearing shells carry considerable load. Connecting-rod bearings are better cooled than are main bearings as a result of the ventilation produced by the rotation of the crankpins. The lubricating oil is usually supplied from the main bearing, being forced through the oil groove and the inclined bores of the crankshaft. Crankpin surface hardness varies from 200 to approximately 350 Brinell and depends on the bearing material hardness. The surface finish of the crankpins should

be as smooth as practicable. These bearings are designed with clearance ratios varying from 0.0007 to 0.0015 inch per inch of diameter. Smaller values are used in four-cycle Diesel-engine bearings.

Main Bearings.—Maximum pressures are moderate and may reach values of approximately 1500 pounds per square inch. The loading of these bearings is due to gas, inertia, and centrifugal forces. The lower bearing shell is usually more highly loaded than the upper. These bearings are lubricated with cool lubricating oil direct from the heat exchanger and header. Main-journal surface hardness is the same as that of crankpins. These bearings are designed with clearance ratios varying from 0.0008 to 0.0015 inch per inch of diameter.

Other Diesel-engine Bearings.—Camshaft, gear, pump, and auxiliary machinery bearings, which operate as power bearings, are not heavily loaded and cause very little trouble when properly lubricated.

Common Diesel-engine Bearing Failures.

Failures may be caused by one or more of the following:—

1. Fatigue of bearing metal under high cyclic loads.
2. Excessive or insufficient hardness of the bearing material.
3. Corrosion of the bearing metal by the lubricating oil.
4. Inadequate bond between bearing metal and bearing shell.
5. Assembly errors.
6. Foreign particles.
7. Miscellaneous, such as defective manufacture, extrusion, wiping, etc.

Fatigue Failures.—Fatigue failures in heavy-duty bearings are usually produced by the cyclic peak loads and improper or loose fits of the shells in their housings. This means that a definite bearing area is pounded by the peak load every cycle, and if the physical properties of the bearing material, such as compressive strength and brittleness, are inadequate, fatigue failure may follow. Numerous small cracks, of mosaic pattern, on the bearing surface are the first indication of fatigue distress. With time, and under additional pounding, the cracks will increase in number and size. The depth of these cracks also will increase and may penetrate the entire bearing-material thickness, thus reaching the bearing shell. In such cases, some sections of the bearing material may be lifted by the high hydrostatic oil pressure, resulting in a partial loss of the bearing surface.

Not every bearing which shows fatigue failures should be replaced. A bearing may be replaced if fatigue failure has reduced its effective bearing area by more than 10 per cent. Bearings with fatigue failures should be carefully inspected, and if it is considered that they may continue to operate, all sharp babbitt edges around the failures must be rounded by a scraper or a small electric iron in order to prevent any additional breaking off of the babbitt. Inspections of such bearings are necessary in order to ascertain that the failures are not progressing.

Hardness of Bearing Materials.—The chemical specifications of several heavy-duty Diesel-engine bearing materials are given in Figure 1. Bearing materials should conform closely to these specifications. The Brinell hardness of cadmium-base, copper-lead base, and tin-base bearing materials is plotted against temperature in Figure 2. Since the Brinell hardness is proportional to the compressive strength, this graph is doubly important.

The region of temperatures of particular interest is between 200 and 300 F., indicated by the double ordinate lines. The cadmium-base alloys are rather hard at room temperature and rapidly lose their physical properties with increasing temperature, as indicated by the steep curve. The copper-lead mixtures retain their hardness and physical properties almost unchanged in the region of temperatures plotted. In the group of white bearing metals, comprising Satco, tin-base and lead-base babbitts, Satco possesses the highest physical properties at elevated temperatures.

The trimetal or "sandwich-type" bearing is composed of a 0.006 to 0.008 inch thick layer of tin-base or lead-base babbitt bonded to an approximately

BEARING MATERIAL	TIN Sn	LEAD Pb	ANTIMONY Sb	COPPER Cu	CADMIUM Cd	SILVER Ag	NICKEL Ni	ARSENIC As	CALCIUM Ca	ALUMINUM Al	ZINC Zn	MAGNESIUM Mg	IRON Fe	OTHERS
CADMIUM-SILVER SAE NO. 810	0.01	0.02		0.50	98.0	1.00	-	-	-	-	0.02	-	-	REM.
CADMIUM-NICKEL SAE NO. 10	0.10	0.01	0.10	0.04	97.8		1.90	-	-	-	-	-	-	REM.
COPPER-LEAD	-	25.0	-	75.0	-	-	-	-	-	-	-	-	-	-
LEAD-BASE BABBITT SAE GRADE NO. 5	5.00	80.0	15.0	0.30	-	-	-	0.20	-	-	-	-	-	REM.
SATCO	1.00	98.0	-	-	-	-	-	-	0.50	0.07	-	0.09	0.01	REM.
TIN-BASE BABBITT SAE GRADE NO. 2	88.0	0.35	7.50	4.00	-	-	-	0.10	-	-	-	-	0.03	REM.

FIG. 1.—CHEMICAL COMPOSITION OF REPRESENTATIVE BEARING MATERIALS.

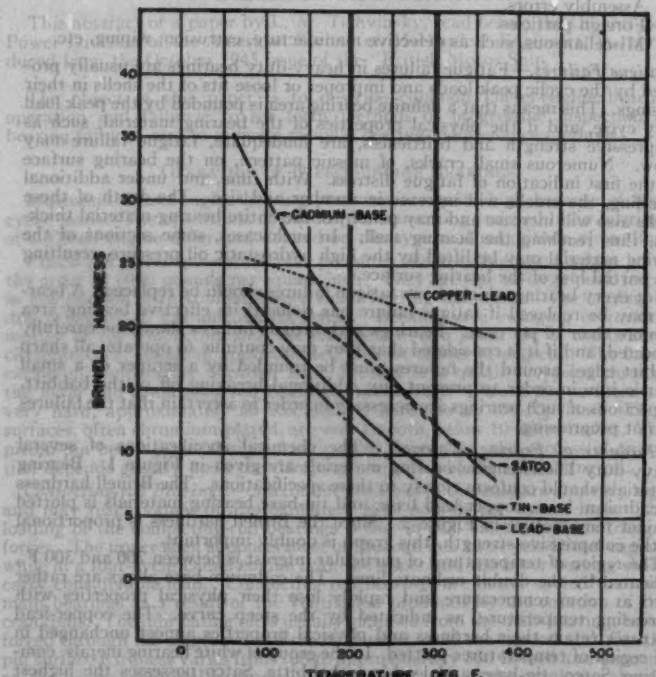


FIG. 2.—HARDNESS-TEMPERATURE RELATIONSHIPS OF VARIOUS BEARING ALLOYS.

0.020 inch thick intermediate layer of bronze, which, in turn, is bonded to a steel back.

Too hard a bearing material may score the journal surface, while too soft a material may yield under the bearing pressure.

Corrosion of Bearing Alloys.—Corrosion of bearing materials is due to chemical action of oxidized lubricating oils and can usually be identified by rough and pitted surfaces. In most cases corrosion occurs over small areas of the bearing and is associated with high localized temperatures.

In one instance, corrosion of Satco occurred over approximately 50 per cent of the bearing area during the first 24 hours of operation of the bearing. It is believed that this corrosion was produced by a small amount of sulphuric acid which formed in the crankcase when sulphur trioxide from the fuel mixed with water condensate while the engine was secured (shut down).

Corrosion of a cadmium-nickel bearing was recorded during a pre-trial inspection. Since the most intense corrosion occurred next to the copper-deposited flange, it is believed that copper might have acted as a catalyst during the initial running-in period, for the bearing was reinstalled and operated in the engine for a total of 2258 hours without any additional corrosion. It is believed that the corrosion was due to the presence of foreign matter between the bearing back and housing, resulting, initially, in a local decreased bearing clearance and a local temperature rise.

Tin-base babbitt, which has very high corrosion resistance, is usually called a non-corrosive babbitt. However, under unusual and adverse conditions it may corrode.

Because of corrosion, the bearing load-carrying surface may be considerably decreased. This may require replacement of the bearing especially if the effective bearing surface becomes reduced to such an extent that wiping occurs.

Bond Strength Between Bearing Lining and Shell.—Poor bond between the bearing lining and the shell metal is a rather frequent cause of bearing failure and, in most cases, is due to defective manufacture. The heat flow through a poor bond area is usually impeded and may lead to failure because of uneven and excessive bearing-surface temperature. Fatigue cracks occurring over poor bond areas will loosen the bearing lining quickly.

Poor bond in cases of trimetal or "sandwich"-type bearings may occur also between the intermediate bronze layer and steel of the shell. Non-metallic inclusions between the bronze and the steel will decrease the heat flow from the bronze to the steel, and local overheating may result. Such manufacturing defects cannot be detected by routine inspection and are found usually after a bearing failure.

Areas of poor bond of a failed bearing are usually found to be without any trace of bonding alloy.

Faulty Assembly.—Assembly errors occur from time to time and are usually caused by negligence and lack of experience. Faulty assembly of a small bearing shell in which the locking lip may not fit the recess in the bearing can produce excessive distortion which causes bearing failure.

A well-known example of faulty assembly of a connecting-rod bearing is the mounting of the upper grooveless shell in the place of the lower shell, which is machined with an oil groove. This results in a complete interruption of the oil flow.

Another example of faulty assembly occurs when the outside surface of an upper main bearing shell seizes to its cap. This seizure, or local welding of small areas and transfer of metal, is due to working of the shell in its cap at the bearing split. This working is possible because of excessive original side clearance between the cap and the saddle. Local, minor seizure may also occur on the outside cap fit.

SOME SIMPLIFIED HEAT TRANSFER DATA.

This paper by Margaret Fishenden and O. A. Saunders is reproduced from the "Journal of the Institute of Fuel" for December 1945. It presents basic data on heat transfer in a readily useable form for the practical designer.

Introduction.

Even a very limited field of inquiry, such as industrial wa te heat recovery, involves heat transfer problems of almost every type. But despite the advances of the last 15 years, heat transmission is still a difficult subject for engineers, not because there is anything specially obscure about it, but because of the wide gap between the conditions of practice and those under which scientifically controlled measurements are carried out. Thus, the basic data, which have usually been obtained only for certain simple geometrical arrangements, and under defined conditions, are not as a rule strictly applicable to the much more complicated design and conditions of actual industrial plant. In consequence, assumptions and approximations have to be made which, without experience, may entail serious errors.

The aims of the fundamental paper on heat transfer in this series must inevitably be very restricted, and it was thought best to concentrate on presenting some of the basic data in more easily usable forms, so that the practical designer's already difficult task should not be further hampered by unnecessary detail. Actual heat transfer coefficients, which can be read off directly from curves, have therefore been worked out for some of the most important cases, but before giving these coefficients, it may perhaps be helpful to give a brief outline of the more comprehensive "similarity" methods of correlation upon which they are largely based.

Use of Dimensionless Numbers, or Groups.

In presenting experimental data, especially of heat transfer by convection, it is now customary to economize in variables by grouping them together in arrangements known as dimensionless numbers, or dimensionless groups. A dimensionless number is the ratio of two like quantities, for example, a velocity to a velocity, a force to a force, or an energy to an energy, which determines the behavior of any given system, whether mechanical, physical, or of any other nature. To take a very simple example: suppose an object is acted on simultaneously by two forces in given directions. The direction in which the object will tend to move will depend upon the ratio of the strengths of the two forces. In other words, this ratio is the dimensionless number governing this particular problem.

To take another example, the flow of a fluid past a solid body of given shape is determined by the ratio of the inertia of the oncoming fluid to the viscous drag. The inertia is proportional to the mass flow, ρv, multiplied by the velocity v, i.e., to ρv^2: the viscous drag is proportional to the viscosity of the fluid, μ, multiplied by the velocity gradient, v/l, i.e., to $\mu v/l$. The ratio of these is $\rho v l/\mu$, well known as the Reynolds number, l being any typical linear dimension. The flow depends also upon the shape of the body, which can be expressed by ratios of length to length, all dimensionless; it can thus be said to be governed by the Reynolds number, so long as only one shape is considered at a time.

The practical value of dimensionless numbers in such problems as convection lies in the fact that a study of the fundamental processes involved enables one, even before doing any experiments, to predict the dimensionless numbers—that is, the ratios of certain pairs of energies, or forces or diffusivities, etc., by which the problem is likely to be determined. Since the dimensionless numbers are usually much fewer than their constituent variables, experimental work is reduced by their use, and the presentation of the results is simplified.

As well as dimensionless numbers consisting of known independent variables, dimensionless numbers containing unknowns whose values require to be found may be formed. For example, the drag exerted upon a body in a stream of fluid, can be put in a dimensionless number by taking the ratio of the drag per unit area, R/l^2, to the inertia, ρv^2, giving $R/\rho v^2 l^2$. This number contains the unknown R as well as the known quantities ρ, v, and l, and we can assert that $R/\rho v^2 l^2$ depends only upon the Reynolds number, $v\rho l/\mu$ for any given shape of body.

In convection, the most important dimensionless numbers consisting solely of known independent variables are:—

The Reynolds number, Re, or $vl\rho/\mu$, which determines the character of the flow of fluid past any body—for example, flow through a tube of diameter l.

The Prandtl number, Pr, sometimes known as the Stanton number, given by $c\mu/k$. This number is the ratio of the momentum diffusivity, or kinematic viscosity, μ/ρ, to the heat diffusivity, $k/c\rho$. The Prandtl number and the Reynolds number together determine the flow of heat in a convecting fluid. For example, the velocity distribution in the fluid flowing through a pipe is determined by Re, and the temperature distribution by both Re and Pr.

The most important dimensionless number in heat transfer containing an unknown whose value is required, is the Nusselt number, Nu, or $Hl/k\theta$ which contains the unknown heat flow per unit area of surface H. For forced convection, Nu depends on both Re and Pr. Other dimensionless numbers are associated with natural convection, condensation, evaporation, etc.

The Complex Nature of Heat Transmission.

In any system where there are temperature differences from one place to another, heat is transferred from the hotter to the cooler parts which are not in contact with one another by both radiation and convection, and sometimes also by evaporation and condensation. It is transferred from the hotter to the cooler parts which are in contact with one another by conduction, and for partially transparent bodies also by radiation. Sometimes one method of communication may be the more important; sometimes another, but with the quantitative heat transfer hidden in complicated formulae it is not always easy for the uninitiated, without a good deal of tedious arithmetic work, to decide which.

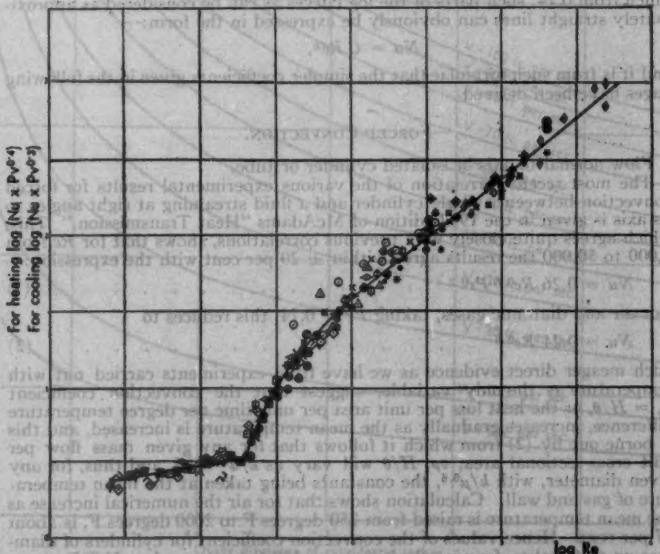


Fig. 1.—*Correlation of experimental results of convection for a fluid flowing through a tube.*

Thus, radiation from one solid surface to another is given approximately by $\sigma E(T_1^4 - T_2^4)$, where T_1 and T_2 are their absolute temperatures, σ is Stefan's constant and E is an "effective emissivity," which may involve both E_1 and E_2, the emissivities of the two surfaces. These themselves vary with temperature, as well as with both the nature and the condition of the surfaces. Forced convection is, in simplified form, given by $C(T_1 - T_2) \times v^n$ where both C, and n depend upon size, shape and position, upon Re, and to a lesser degree upon the absolute temperatures. Natural convection is given by $C(T_1 - T_2)^m$ where both C and m again depend upon size, shape, and position, and to some extent upon absolute temperature.

Thus, for dealing quickly with practical problems, it is essential to use simplifications, and the most convenient method is probably to determine coefficients for different cases, by which the temperature difference must be multiplied to give the heat transfer per unit area per unit time. Sometimes these must be used to determine separately the heat transferred by radiation and convection, sometimes composite coefficients, which include both radiation and convection can be used. It is, of course, not feasible to deal in this way with more than a very limited number of shapes; indeed, this is all the available data allow.

Forced convection.—In heat exchangers the most important cases of forced convection appear to be flow through a tube, flow at right angles to the outside of a tube, and flow across tube banks, where there is a limited amount of information for oblique, as well as for normal flow.

The initial correlations of the experimental results for forced convection have of course been by dimensionless methods. Usually Nu times some power of Pr has been plotted against Re on a logarithmic scale. Such a correlation is shown in Figure 1 for flow of liquids and gases through tubes. Similar correlations have appeared in the standard books on heat transfer for flow across tubes. For gases, for which Pr can be omitted, since it seldom varies much from 0.74, such parts of the log curves as can be considered as approximately straight lines can obviously be expressed in the form:—

$$Nu = C\,Re^n,$$

and it is from such formulae that the simpler coefficients given in the following pages have been derived.

Forced Convection.

Flow normal to axis of isolated cylinder or tube.

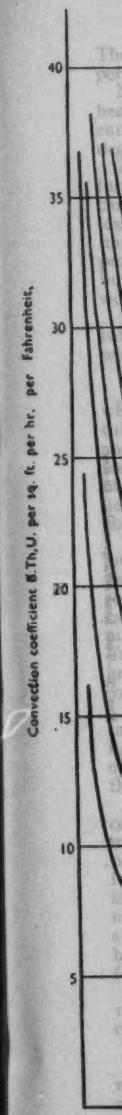
The most recent correlation of the various experimental results for forced convection between a single cylinder and a fluid streaming at right angles to its axis is given in the 1942 edition of McAdams "Heat Transmission." This, which agrees quite closely with previous correlations, shows that for Re from 1,000 to 50,000 the results agree within ± 20 per cent with the expression:—

$$Nu = 0.26\,Re^{0.6}\,Pr^{0.3} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

For air and diatomic gases, taking $Pr = 0.74$, this reduces to

$$Nu = 0.24\,Re^{0.6} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Such meager direct evidence as we have from experiments carried out with temperature as the only variable, suggest that the convection coefficient α, $= H/\theta$, or the heat loss per unit area per unit time per degree temperature difference, increases gradually as the mean temperature is increased, and this is borne out by (2) from which it follows that for any given mass flow per unit cross-sectional area, $v\rho$, H/θ will vary as $k/d^{0.4}\,\mu^{0.6}$, and thus, for any given diameter, with $k/\mu^{0.6}$, the constants being taken at the mean temperature of gas and wall. Calculation shows that for air the numerical increase as the mean temperature is raised from 250 degrees F. to 2000 degrees F. is about 57 per cent. Hence values of the convection coefficient for cylinders of diameter up to 6 inches, for air velocities up to 100 feet a second at N.T.P., have been computed from expression (2) for a mean temperature of 250 degrees F.



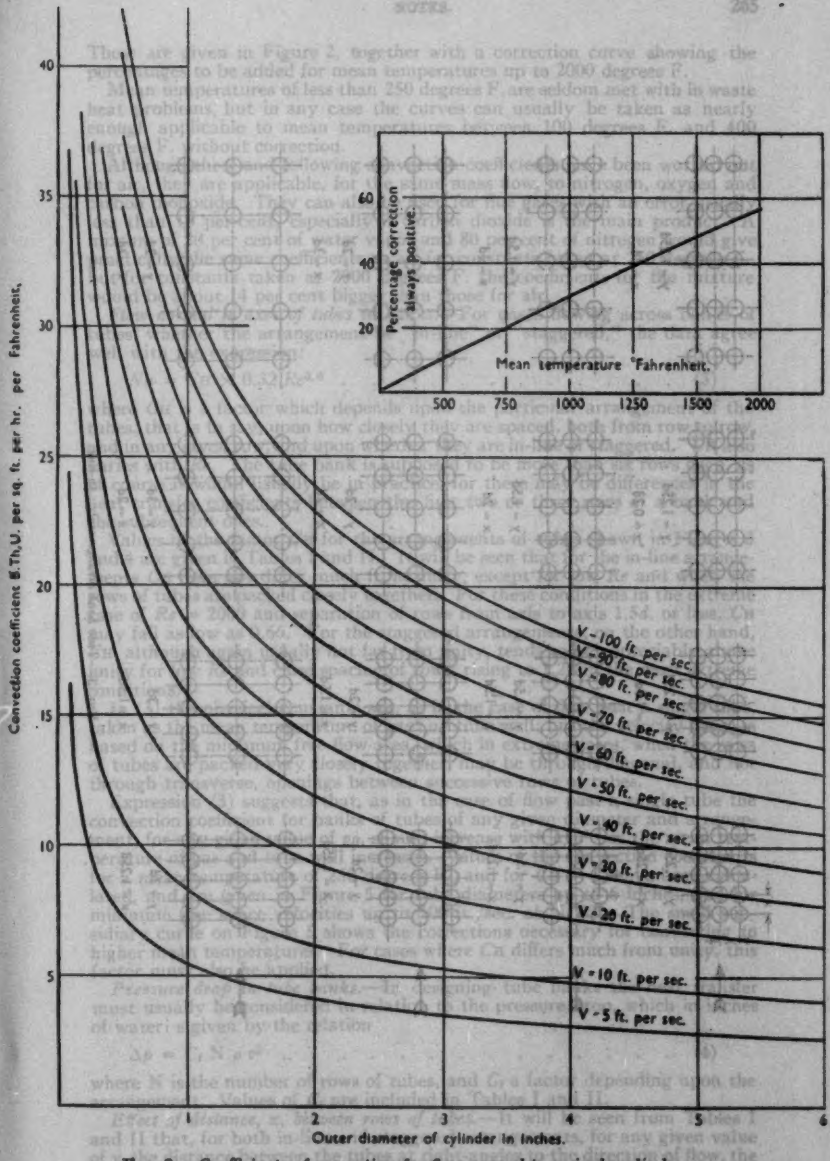


FIG. 2.—*Coefficients of convection for flow normal to a single cylinder.*

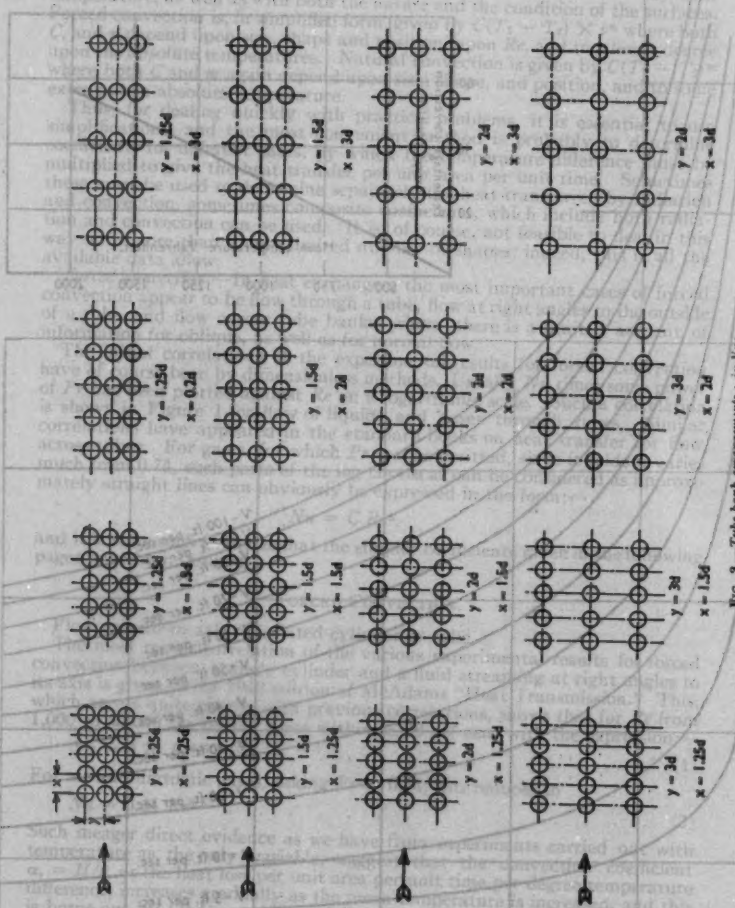


FIG. 3.—*Tube bank arrangements : in-line.*

These are given in Figure 2, together with a correction curve showing the percentages to be added for mean temperatures up to 2000 degrees F.

Mean temperatures of less than 250 degrees F. are seldom met with in waste heat problems, but in any case the curves can usually be taken as nearly enough applicable to mean temperatures between 100 degrees F. and 400 degrees F. without correction.

Although these and following convection coefficients have been worked out for air, they are applicable, for the same mass flow, to nitrogen, oxygen and carbon monoxide. They can also be used for flue gases with an error usually less than 10 per cent, especially if carbon dioxide is the main product. A mixture of 20 per cent of water vapor and 80 per cent of nitrogen would give practically the same coefficients as air for constants taken at 250 degrees F., but for constants taken at 2000 degrees F. the coefficients for the mixture would be about 14 per cent bigger than those for air.

Flow normal to axes of tubes in banks.—For gases flowing across banks of tubes, whether the arrangement be "in-line" or "staggered," the data agree well with the expression:

$$Nu = C_H \times 0.32\, Re^{0.6} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

where C_H is a factor which depends upon the particular arrangement of the tubes, that is to say, upon how closely they are spaced, both from row to row, and in any given row, and upon whether they are in-line or staggered. C_H also varies with Re. The tube bank is supposed to be more than six rows deep, as of course it would usually be in practice, for there may be differences in the heat transfer coefficients between the first two or three rows of a bank and the subsequent ones.

Values of the factor C_H for the arrangements of tubes shown in Figures 3 and 4 are given in Tables I and II. It will be seen that for the in-line arrangements C_H does not differ much from unity, except for low Re and when the rows of tubes are packed closely together. For these conditions in the extreme case of $Re = 2000$ and separation of rows from axis to axis $1.5d$. or less, C_H may fall as low as 0.66. For the staggered arrangements, on the other hand, C_H, although again usually not far from unity, tends to be appreciably above unity for low Re and close spacing of rows, rising to 1.26 in the most extreme conditions.

In (3) the physical constants are, as in the case of flow past a single tube, taken as the mean temperature of gas and tube wall; but the velocity taken is based on the minimum free-flow area, which in extreme cases, when the rows of tubes are packed very closely together, may be through diagonal, and not through transverse, openings between successive rows of tubes.

Expression (3) suggests that, as in the case of flow past a single tube the convection coefficient for banks of tubes of any given diameter and arrangement, for any given value of vp, should increase with $k/\mu^{0.6}$ as the mean temperature of gas and tube wall increases. Values of the convection coefficients for a mean temperature of 250 degrees F., and for $C_H = 1$, have been calculated, and are given in Figure 5 for tube diameters up to 6 inches, and for minimum free space velocities up to 100-ft./sec. at N.T.P. The small subsidiary curve on Figure 5 shows the corrections necessary for converting to higher mean temperatures. For cases where C_H differs much from unity, this factor must also be applied.

Pressure drop in tube banks.—In designing tube banks the heat transfer must usually be considered in relation to the pressure drop, which in inches of water is given by the relation

$$\Delta p = C_f\, N\, \rho\, v^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

where N is the number of rows of tubes, and C_f a factor depending upon the arrangement. Values of C_f are included in Tables I and II.

Effect of distance, x, between rows of tubes.—It will be seen from Tables I and II that, for both in-line and staggered arrangements, for any given value of y, the distance between the tubes at right-angles to the direction of flow, the ratio of the heat transfer factor, C_H, to the friction factor C_f, decreases rapidly

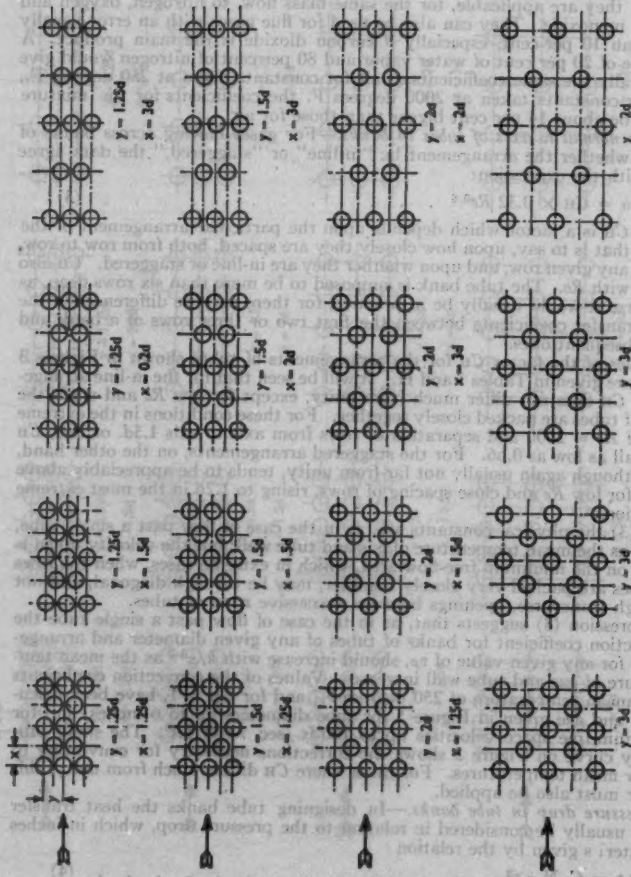


FIG. 4.—Tube bank arrangements : staggered.

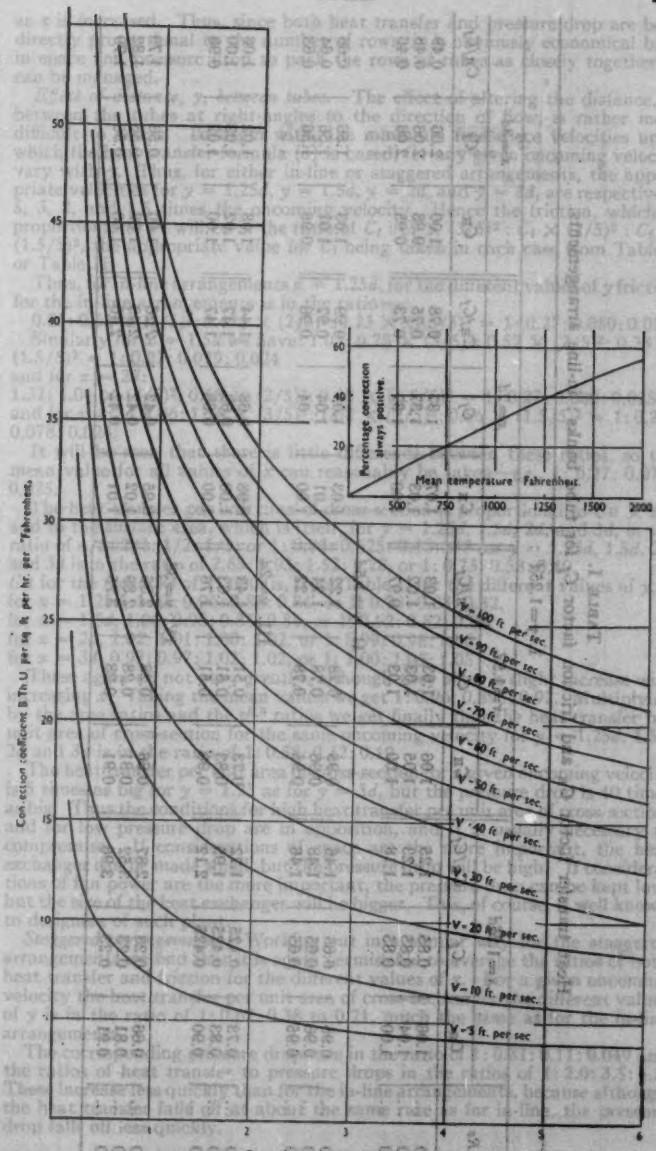

Convection coefficient B Th U per sq ft per hr per °Fahrenheit.
Outer diameter of cylinder or inches
V = 100 ft. per sec.
V = 90 ft. per sec.
V = 80 ft. per sec.
V = 70 ft. per sec.
V = 60 ft. per sec.
V = 50 ft. per sec.
V = 40 ft. per sec.
V = 30 ft. per sec.
V = 20 ft. per sec.
V = 10 ft. per sec.
V = 5 ft. per sec
Percentage correction always positive.
Mean temperature Fahrenheit.

FIG. 5.—*Coefficients of convection for flow past tube banks.*

TABLE I.

Heat transfer factor C_H and friction factor C_f for tube banks: in-line arrangements.

I. $y=1.25d$

Re	$x=1.25d$			$x=1.5d$			$x=2d$			$x=3d$		
	C_H	C_f	C_H/C_f	C_H	C_f	C_H/C_f	C_H	C_f	C_H/C_f	C_H	C_f	C_H/C_f
2000 ...	1.06	0.85	1.25	1.06	1.03	1.03	1.07	1.37	0.78	1.00	2.06	0.49
8000 ...	1.04	0.85	1.23	1.05	1.03	1.02	1.03	1.37	0.75	0.98	2.06	0.48
20000 ...	1.00	0.85	1.18	1.00	1.03	0.97	1.00	1.37	0.73	0.95	2.06	0.46
II. $y=1.5d$												
2000 ...	0.95	0.65	1.46	0.95	0.78	1.22	1.03	1.04	0.99	1.03	1.56	0.66
8000 ...	0.96	0.65	1.48	0.96	0.78	1.24	1.01	1.04	0.97	1.01	1.56	0.64
20000 ...	0.95	0.65	1.46	0.95	0.78	1.22	1.00	1.04	0.96	0.98	1.56	0.63
III. $y=2d$												
2000 ...	0.73	0.425	1.72	0.73	0.51	1.43	0.98	0.68	1.44	1.08	1.02	1.06
8000 ...	0.83	0.425	1.95	0.83	0.51	1.63	1.00	0.68	1.47	1.02	1.02	1.00
20000 ...	0.90	0.425	2.12	0.90	0.51	1.76	1.00	0.68	1.47	1.00	1.02	0.98
IV. $y=3d$												
2000 ...	0.66	0.23	2.87	0.66	0.28	2.36	0.95	0.42	2.26	1.00	0.56	1.79
8000 ...	0.81	0.23	3.52	0.81	0.28	2.89	1.02	0.42	2.43	1.02	0.56	1.82
20000 ...	0.91	0.23	3.96	0.91	0.28	3.25	1.01	0.42	2.40	1.00	0.56	1.79

as x is increased. Thus, since both heat transfer and pressure drop are both directly proportional to the number of rows, it is obviously economical both in space and pressure drop to pack the rows of tubes as closely together as can be managed.

Effect of distance, y, between tubes.—The effect of altering the distance, y, between the tubes at right-angles to the direction of flow, is rather more difficult to assess. To begin with, the minimum free space velocities upon which the heat transfer formula (3) is based, for any given oncoming velocity vary with y. Thus, for either in-line or staggered arrangements, the appropriate velocities for $y = 1.25d$, $y = 1.5d$, $y = 2d$, and $y = 3d$, are respectively 5, 3, 2, and 1.5 times the oncoming velocity. Hence the friction, which is proportional to v^2, will be in the ratio of $C_f : C_f \times (3/5)^2 : C_f \times (2/5)^2 : C_f \times (1.5/5)^2$, the appropriate value for C_f being taken in each case from Table I or Table II.

Thus, for in-line arrangements $x = 1.25d$, for the different values of y friction for the in-line arrangements is in the ratio:—

$0.85 : 0.65 \times (3/5)^2 : 0.425 \times (2/5)^2 : 0.23 \times (1.5/5)^2 = 1 : 0.27 : 0.080 : 0.025.$

Similarly for $x = 1.5d$ we have: $1.03 : 0.78 \times (3/5)^2 : 0.57 \times (2/5)^2 : 0.28 \times (1.5/5)^2 = 1 : 0.27 ; 0.079 : 0.024$

and for $x = 2d$:

$1.37 : 1.04 \times (3/5)^2 : 0.68 \times (2/5)^2 : 0.42 \times (1.5/5)^2 = 1 : 0.27 : 0.080 : 0.028$

and for $x = 3d$ $2.06 : 1.56 \times (3/5)^2 : 1.02 \times (2/5)^2 : 0.56 \times (1.5/5)^2 = 1 : 0.27 : 0.078 : 0.024$.

It will be seen that there is little difference between these ratios, so the mean value for all values of x can reasonably be taken—*i.e.*, 1 : 0.27 : 0.079 : 0.025.

The heat transfer per unit area of cross-section is proportional to $C_H \times v^{0.6}$ and to the surface area, which is itself, for $y = 1.25d$, $1.5d$, $2d$, and $3d$, in the ratio of 4/5 : 2/3 : 1/2 : 1/3 : or 1 : 0.83 : 0.625 : 0.42 : $v^{0.6}$ for $y = 1.25d$, $1.5d$, $2d$, and $3d$ is in the ratio of 2.63 : 1.93 : 1.52 : 1.28, or 1 : 0.73 : 0.58 : 0.49.

C_H for the mean Re of 11,000, is, from Table I, for the different values of y,

for $x = 1.25d$, 1.03 : 0.96 : 0.85 : 0.84, or 1 : 0.93 : 0.83 : 0.82.

for $x = 1.5d$, 1.04 : 0.96 : 0.85 : 0.84, or 1 : 0.92 : 0.82 : 0.81.

for $x = 2d$, 1.02 : 1.01 : 1.00 : 1.02, or 1 : 0.99 : 0.98 : 1.00

for $x = 3d$, 0.97 : 0.97 : 1.02 : 1.02, or 1 : 1.00 : 1.05 : 1.05

These again do not vary greatly, although they show a slight increase with increasing x. Taking the mean values we get 1 : 0.96 : 0.895 : 0.92. Multiplying by the area ratios and the $v^{0.6}$ ratios we get finally that the heat transfer per unit area of cross-section for the same oncoming velocity for $y = 1.25d$, $1.5d$, $2d$ and $3d$ is in the ratio of 1 : 0.58 : 0.32 : 0.19.

The heat transfer per unit area of cross-section for a given oncoming velocity is 5 times as big for $y = 1.25$ as for $y = 3d$, but the pressure drop is 40 times as big. Thus the conditions for high heat transfer per unit area of cross-section, and for low pressure drop are in opposition, and it is usually necessary to compromise. If considerations of space are the more important, the heat exchanger can be made small, but the pressure drop will be high. If considerations of fan power are the more important, the pressure drop can be kept low, but the size of the heat exchanger will be bigger. This, of course, is well known to designers of such plant.

Staggered arrangements.—Working out in a similar way for the staggered arrangements we find that it is again permissible to average the ratios of both heat transfer and friction for the different values of x. For a given oncoming velocity the heat transfer per unit area of cross-section for the different values of y is in the ratio of 1 : 0.62 : 0.38 to 0.21, much the same as for the in-line arrangements.

The corresponding pressure drops are in the ratio of 1 : 0.31 : 0.11 : 0.049 and the ratios of heat transfer to pressure drops in the ratios of 1 : 2.0 : 3.5 : 4.3. These increase less quickly than for the in-line arrangements, because although the heat transfer falls off at about the same rate as for in-line, the pressure drop falls off less quickly.

TABLE II.

Heat transfer factor C_H and friction factor C_f for tube banks : staggered arrangements.

Re	$x=1.25d$			$x=1.5d$			$x=2d$			$x=3d$		
	C_H	C_f	C_H/C_f	C_H	C_f	C_H/C_f	C_H	C_f	C_H/C_f	C_H	C_f	C_H/C_f
I. $y=1.25d$												
2000 ...	1.21	1.74	0.70	1.16	1.74	0.67	1.06	1.74	0.61	0.96	1.74	0.55
8000 ...	1.11	1.74	0.64	0.99	1.74	0.57	0.92	1.74	0.53	0.95	1.74	0.55
20000 ...	1.06	1.74	0.61	1.05	1.74	0.60	1.02	1.74	0.58	0.93	1.74	0.53
II. $y=1.5d$												
2000 ...	1.17	1.51	0.77	1.15	1.51	0.76	1.08	1.51	0.72	1.02	1.51	0.68
8000 ...	1.10	1.51	0.73	1.06	1.51	0.71	1.00	1.51	0.67	0.96	1.51	0.64
20000 ...	1.04	1.51	0.69	1.02	1.51	0.68	0.98	1.51	0.65	0.94	1.51	0.62
III. $y=2d$												
2000 ...	1.22	1.20	1.02	1.18	1.20	0.98	1.12	1.20	0.93	1.08	1.20	0.90
8000 ...	1.12	1.20	0.93	1.10	1.20	0.92	1.04	1.20	0.87	1.01	1.20	0.84
20000 ...	1.09	1.20	0.91	1.07	1.20	0.89	1.01	1.20	0.84	0.97	1.20	0.81
IV. $y=3d$												
2000 ...	1.26	0.95	1.33	1.26	0.95	1.33	1.18	0.95	1.24	1.13	0.95	1.19
8000 ...	1.16	0.95	1.22	1.16	0.95	1.22	1.11	0.95	1.17	1.06	0.95	1.12
20000 ...	1.14	0.95	1.20	1.13	0.95	1.19	1.10	0.95	1.16	1.02	0.95	1.07

TABLE III.

Ratio of C_H/C_f in-line to C_H/C_f staggered.

	$x=1.25d$	$x=1.5d$	$x=2d$	$x=3d$
I.—$y=1.25d$	1.22/0.65=1.88	1.01/0.61=1.66	0.75/0.57=1.32	0.48/0.54=0.89
II.—$y=1.5d$	1.47/0.73=2.01	1.23/0.72=1.71	0.97/0.68=1.43	0.64/0.65=0.99
III.—$y=2d$	1.93/0.95=2.03	1.61/0.93=1.73	1.46/0.88=1.66	1.01/0.85=1.19
IV.—$y=3d$	3.45/1.25=2.76	2.83/1.25=2.27	2.36/1.19=1.98	1.80/1.10=1.64

Comparison of in-line and staggered arrangements.—It will be seen from Table III, which gives the ratios of C_H/C_t, in-line, to C_H/C_t, staggered, that for almost the whole range of values of x and y C_H/C_t, in-line, is bigger than C_H/C_t, staggered, the ratio increasing as y increases, and as x decreases. It varies from 2.76 for $y = 3d$ and $x = 1.25d$, to 0.89 for $y = 1.25d$ and $x = 3d$. On the other hand, the actual values of C_H tend to be somewhat bigger for the staggered arrangements than for the in-line, especially for big values of y and small values of x. The excess is about 50 per cent for the extreme case of $y = 3d$, $x = 1.25d$. It is the old conflict between heat transfer and pressure drop for any given cross-section. Other things being the same, staggered arrangements are likely to give slightly greater heat transfer, but usually at a disproportionate increase in the pressure drop.

Effect of angle of impingement of air upon heat transfer in tube banks.—Ornatski made an experimental determination of the heat transfer from steam heated tubes banks to air for angles of impingement from 90 degrees to 30 degrees. The tubes were in-line with both x and $y = 2d$. The diameter of the tubes was 4/5 inch and the range of Re investigated 5000 to 16,000. The results were given in the form Nu = constant $\times$ Re^n, with varying values of both the constant and n, but they can be transformed with no appreciable error to Nu = Constant $\times$ $Re^{0.6}$. For an angle of 90 degrees a bank of 7 rows of tubes gave $Nu = 0.32\ Re^{0.6}$, which agrees with the formula already given—*i.e.*, $Nu = 0.32\ C_H\ Re^{0.6}$, since it will be seen from Table I that for this case $C_H = 1$.

For angles of 80 degrees, 70 degrees, 60 degrees, 45 degrees, and 30 degrees the values of Ornatski's constant are 0.30, 0.31, 0.28, 0.25, and 0.19 respectively.

Lokshin carried out a similar series of experiments for both in-line and staggered arrangements of electrically-heated tubes for Re from 10,000 to 40,000 and spacing nearly the same as above. For rows after the first his constants for angles of 90 degrees, 80 degrees, 70 degrees, 60 degrees, 45 degrees, 30 degrees, and 15 degrees are 0.27, 0.27, 0.28, 0.27, 0.22, 0.18, 0.12 when corrected to a $Re^{0.6}$ law. For staggered arrangements with the same spacing the corresponding values are 0.32, 0.32, 0.31, 0.29, 0.25, 0.20, 0.13 for rows beyond the first four. Since it will be seen from Table II that for this case also C_H is nearly equal to 1, Lokshin's results for staggered arrangements agree with the results on previous pages. His results for in-line arrangements are slightly low.

Taking both sets of results together it will be seen that until the angle of impingement is below 60 degrees no correction is worth while, but that at 45 degrees the heat transfer is reduced by roughly 20 per cent, and at 30 degrees by 35 or 40 per cent.

Both Ornatski and Lokshin found that the heat transfer in the first row of the in-line banks was about 30 per cent less than the average for subsequent rows. This agrees with the previous American work the difference, however, varying with the spacing. For staggered arrangement, Lokshin found the heat transfer in the first 4 rows was about 12 per cent less than in subsequent rows.

Flow through a tube.—There are some discrepancies in the law of variation of the convection coefficient with temperature in the case of the flow of a fluid through a tube. McAdams obtains a good correlation by plotting Nu against Re, with the physical constants taken at the fluid temperature, which has the advantage that Vp is constant all along the tube. The equation obtained for gases is:—

$$Nu = 0.020\ Re^{0.8} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Taking the constants at the gas temperature of course indicates a variation of the convection coefficient, for a given rate of mass flow, only if the gas temperature is altered, and not if the tube temperature is altered. However, the results correlate quite well with the constants taken at the mean temperature of gas and tube, as in the case of flow across tubes; and there is other evidence that a slight increase in the convection coefficient should follow an increase in mean temperature. The best that can be done thus seems to be to

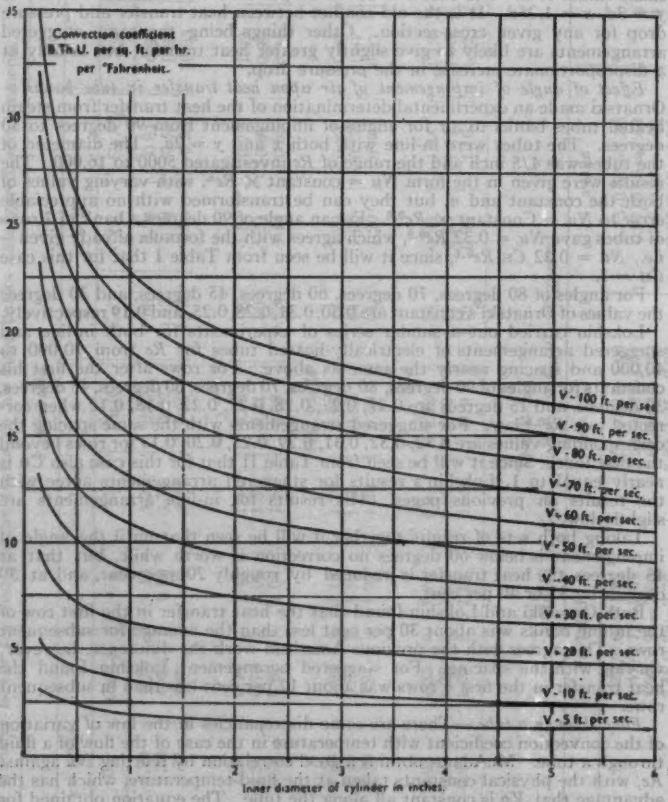


FIG. 8.—*Coefficients of convection for flow through a tube.*

base the law of variation on the mean temperature. This, for small temperature differences, would of course agree with the law indicated by McAdams' expression, and also with the variation suggested by Jung, who more recently made a systematic investigation of the effect of temperature on H/θ for the case of hot combustion gases flowing through tubes.

Convection coefficients have therefore been worked out from (4) taking the physical constants at 250 degrees F. These are given in Figure 6, which includes a small curve of percentage corrections for mean temperatures up to 2000 degrees F.

To settle more precisely the effect of temperature upon convection coefficients, the entire experimental data should really be re-correlated, but this would be a longish job, probably with a return not commensurate with the work involved.

Radiation.

The net radiation from a perfectly black surface at absolute F. temperature T_1 in perfectly black surroundings at absolute F. temperature T_2, is given by $17.3 \times 10^{-10} (T_1^4 - T_2^4)$ Btu./ft.^{2} hr.

For an actual surface of emissivity E_1 and temperature T_1 in surroundings at temperature T_2, in the simplest case, when the surface intercepts no reflected radiation from the surroundings—*i.e.*, when the surroundings are perfectly black, or even if they are not black, when they are relatively large, the expression usually given is $17.3 \times 10^{-10} E_1 (T_1^4 - T_2^4)$. Strictly speaking, this expression applies only to "grey" surfaces, and it does not seem to be generally known that for surfaces whose emissivity changes quickly with temperature its use may result in big percentage errors when T_1 is big and $(T_1 - T_2)$ is small. The correct expression is $17.3 \times 10^{-10} (E_1 T_1^4 - A_1 T_2^4)$, where A_1 is the absorptivity of the surface at T_1 for radiation from the surroundings at T_2.

At the other extreme, when all the radiation reflected from the surroundings is intercepted by the surface at T_1, as in the case of parallel planes large compared with their distance apart, or of concentric cylinders or concentric spheres with the inner surface of the outer cylinder or sphere regularly reflecting, the expression for grey surfaces of emissivity E_1 and E_2 and absolute F. temperature T_1 and T_2 is:—

$$17.3 \times 10^{-10} \frac{E_1 E_2}{E_1 + E_2 - E_1 E_2} (T_1^4 - T_2^4) \text{ Btu./ft.}^2 \text{ hr.} \quad . \quad . \quad (5)$$

As in the previous case, serious errors may arise in taking the grey surface formula for surfaces whose emissivity changes quickly with temperature when T_1 is big and $(T_1 - T_2)$ is small. The correct expression is:—

$$17.3 \times 10^{-10} \left[(E_1 T_1^4 \left(\frac{A_2}{A_2 + E_1 - A_2 E_1} \right) - E_2 T_2^4 \left(\frac{A_1}{A_1 + E_2 - A_1 E_2} \right) \right] \text{ Btu./ft.}^2 \text{ hr.} \quad . \quad . \quad (6)$$

where A_1 is the absorptivity of the surface at T_1 for the radiation from the surface at T_2, and A_2 is the absorptivity of the surface at T_2 for the radiation from the surface at T_1.

In all cases radiation lies between the two limits (*a*) for no interception of reflected radiation; and (*b*) for complete interception of reflected radiation.

Coefficients of radiation.—The coefficient of radiation for a surface of emissivity 1, *i.e.*, a perfectly black surface, at temperature T_1 in black surroundings at T_2 is given by:—

$$17.3 \times 10^{-10} (T_1^4 - T_2^4)/(T_1 - T_2) \text{ Btu./ft.}^2 \text{ hr } ^\circ\text{F.} \quad . \quad . \quad . \quad (7)$$

For small temperature differences, when T_1, T_2 and T_{mean} are nearly equal (7) approaches $17.3 \times 10^{-10} \times T_{mean}^3$. For very large temperature differences it approaches $17.3 \times 10^{-10} T_1^3$.

Coefficients of radiation for values of t_1 up to 2000 degrees F., and for different values of $(t_1 - t_2)$ are given in Figure 7 and Figure 8 for $E = 1$.

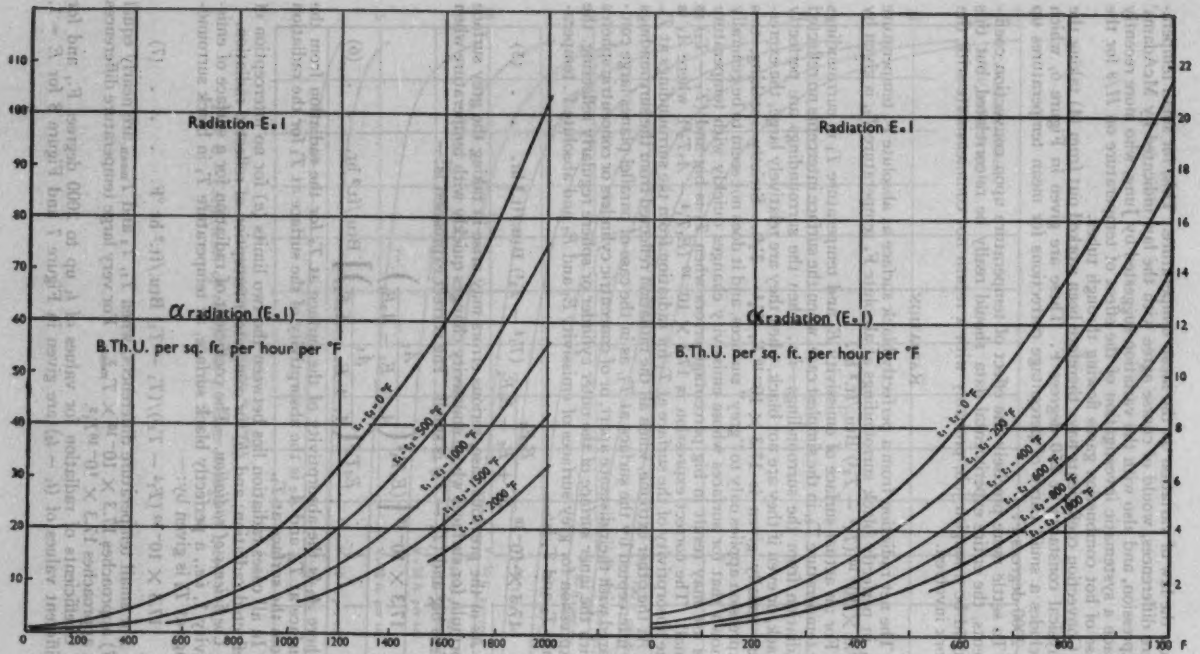


FIG. 7.—*Coefficients of radiation for* E = 1.

FIG. 8.—*Coefficients of radiation for* E = 1 *(magnified scale).*

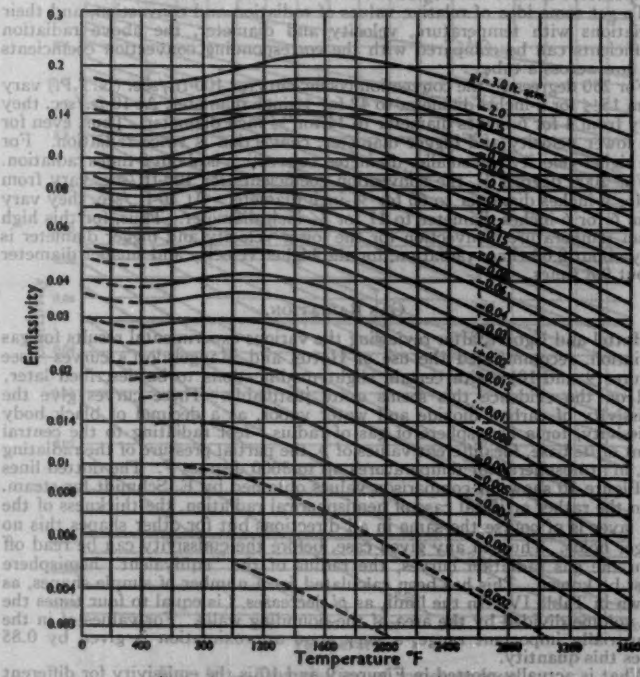


FIG. 9.—*Emissivities of carbon dioxide.*

When the use of the grey surface formulae is justifiable they can be multiplied by the effective emissivity to obtain the coefficient of radiation for any actual case.

It will be seen that, over the range included, the coefficient of radiation for $E = 1$ varies from 0.77 Btu./ft.^{2} hr. degree F. for small differences of temperature around 0 degree F. to 103 Btu./ft.^{2} hr. degree F. for small differences of temperature around 2000 degree F. For an effective emissivity of 0.8, which between these limits of temperature is correct within 20 per cent for many industrial surfaces other than bright metal or nearly white ones, the corresponding coefficients of radiation becomes 0.6 and 80. For small differences of temperature around 250 degrees F. they would be $0.8 \times 2.5 = 2.0$.

To get some idea of relative values of radiation and convection, and their variations with temperature, velocity and diameter, the above radiation coefficients can be compared with the corresponding convection coefficients for flow across a tube.

For 250 degrees F. the convection coefficients for 100-ft./sec. (N.T.P.) vary from 15½ for 6-inches diameter to 42 for ½-inch diameter. At 10-ft./sec. they vary from 4 for 6-inches diameter to 11 for ½-inch diameter. Thus, even for the lower velocity and bigger diameter, convection is twice radiation. For the higher velocity and smaller diameter, convection is about 8 times radiation.

For 2000 degrees F. the convection coefficients for 100-ft./sec. vary from 24 for 6-inches diameter to 66 for ½-inch diameter. At 10-ft./sec. they vary from 6 for 6-inches diameter to 17 for ½-inch diameter. Thus, for this high mean temperature, convection for the lower velocity and bigger diameter is only about 0.08 times radiation, for the higher velocity and smaller diameter about 0.8 times.

Gas Radiation.

Hottel and Egbert, after reviewing the various experimental results for gas radiation, recommended the use of Hottel and Mangelsdorf's curves—(see Figures 9 and 10)—with certain slight modifications to be described later, and on the evidence this seems quite justifiable. These curves give the emissivity of carbon dioxide and water vapor, as a decimal of black body emissivity, for a hemisphere of gas of radius l feet radiating to the central point of its base, for different values of p, the partial pressure of the radiating gas, in atmospheres for temperatures up to 3600 degrees F. The dotted lines on Figure 10 show for comparison values obtained by E. Schmidt for steam.

In the rather artificial case of hemispherical radiation, the thickness of the gas layer is of course the same in all directions but for other shapes this no longer holds. Thus, in any given case, before the emissivity can be read off from the gas radiation curves, the radius of the "equivalent" hemisphere must be known. This has been calculated for a number of simple shapes, as shown in Table IV. In the limit, as pl decreases, l is equal to four times the gas volume divided by the area of the bounding walls. For values of in the industrially important range, a very good approximation is given by 0.85 times this quantity.

What is actually plotted in Figures 9 and 10 is the emissivity for different values of the product pl. By expressing E in terms of pl it is of course tacitly assumed that the radiation depends only upon the total number of radiating molecules, and not upon whether they are spread out over a thicker layer at a lower partial pressure, or squeezed into a thinner layer at a higher partial pressure. But it is known that for water vapor E may depend to an appreciable degree upon p and l separately, as well as upon their product. Above 1200 degrees F. the corrections are small, but below 1200 degrees F. pl should be multiplied by the appropriate factor read off from Figure 11 before using it to determine E from Figure 10. For carbon dioxide no such correction is required.

For water vapor, it will be seen from Figure 11 that the correction to pl may be considerable, but the corresponding correction in the emissive power is much smaller, and the uncertainty in E is not often likely to be greater than

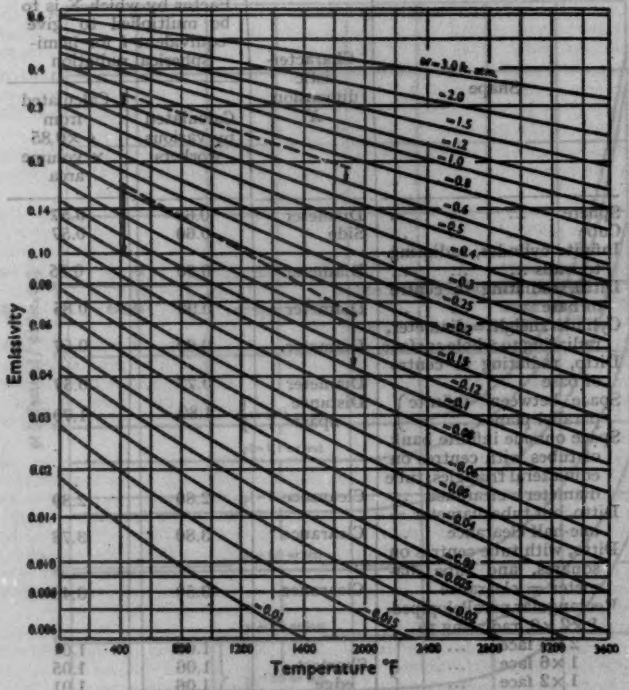


FIG. 10.—*Emissivities of water vapour.*

Table IV

EQUIVALENT THICKNESS *l* FOR NON LUMINOUS GAS RADIATION FROM LAYERS OF DIFFERENT SHAPES

Shape	Characteristic dimension, *X*	Factor by which X is to be multiplied to give equivalent *l* for hemispherical radiation	
		Calculated by various workers	Calculated from $4 \times 0.85 \times \frac{\text{volume}}{\text{area}}$
Sphere	Diameter	0.60	0.57
Cube	Side	0.60	0.57
Infinite cylinder, radiating to walls	Diameter	0.90	0.85
Ditto, radiating to centre of base	Diameter	0.90	0.85
Cylinder, height=diameter, radiating to whole surface	Diameter	0.60	0.57
Ditto, radiating to centre of base	Diameter	0.77	0.57
Space between infinite parallel planes ...	Distance apart	1.80	1.70
Space outside infinite bank of tubes with centres on equilateral triangles, tube diameter=clearance ...	Clearance	2.80	2.89
Ditto, but tube diameter = one-half clearance ...	Clearance	3.80	3.78
Ditto, with tube centres on squares, and tube diameter = clearance ...	Clearance	3.50	3.49
Rectangular parallelopiped, 1 ×2 ×6, radiating to			
2 ×6 face ...	Shortest edge	1.06	1.01
1 ×6 face ...		1.06	1.05
1 ×2 face ...		1.06	1.01
All faces ...		1.06	1.02
Infinite cylinder of semicircular cross-section, radiating to centre of flat side	Diameter	0.63	0.52

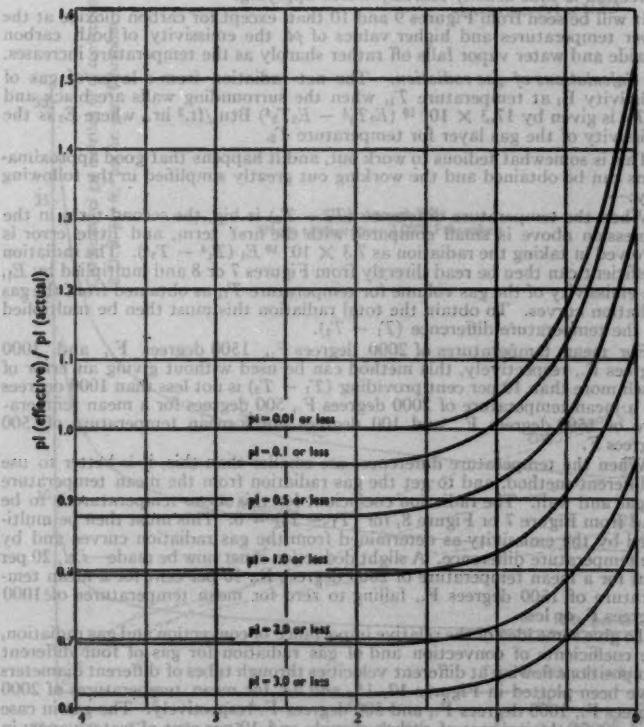


FIG. 11.—*Gas radiation : correction to pl for water.*

the uncertainty of industrial conditions, where gas temperatures, radiating constituents, and other factors may vary both from place to place and from time to time. Moreover, since the emission bands of carbon dioxide and water vapor overlap, either gas absorbs some of the radiation emitted by the other. Hence the emission from, say, flue gases containing both carbon dioxide and water vapor will be less than the calculated sum. Hottel, from direct measurements, and Eckert, from absorption data, have estimated roughly the resulting correction, which varies from zero at very small values of pl to about 10 per cent when pl is 3-ft.-atmospheres. Considering the other uncertainties, this correction is thus usually scarcely worth applying.

It will be seen from Figures 9 and 10 that, except for carbon dioxide at the lower temperatures and higher values of pl, the emissivity of both carbon dioxide and water vapor falls off rather sharply as the temperature increases.

Calculations of gas radiation.—The net radiation from a layer of gas of emissivity E_1 at temperature T_1, when the surrounding walls are black and at T_2, is given by $17.3 \times 10^{-10} (E_1 T_1^4 - E_2 T_2^4)$ Btu./ft.^{2} hr., where E_2 is the emissivity of the gas layer for temperature T_2.

This is somewhat tedious to work out, and it happens that good approximations can be obtained and the working out greatly simplified in the following way:—

When the temperature difference $(T_1 - T_2)$ is big, the second term in the expression above is small compared with the first term, and little error is involved in taking the radiation as $7.3 \times 10^{-10} E_1 (T_1^4 - T_2^4)$. The radiation coefficient can then be read directly from Figures 7 or 8 and multiplied by E_1, the emissivity of the gas volume for temperature T_1, as obtained from the gas radiation curves. To obtain the total radiation this must then be multiplied by the temperature difference $(T_1 - T_2)$.

For mean temperatures of 2000 degrees F., 1500 degrees F., and 1000 degrees F., respectively, this method can be used without giving an error of much more than 10 per cent providing $(T_1 - T_2)$ is not less than 1000 degrees for a mean temperature of 2000 degrees F., 500 degrees for a mean temperature of 1500 degrees F., and 100 degrees for a mean temperature of 500 degrees F.

When the temperature differences are smaller than this, it is better to use a different method, and to get the gas radiation from the mean temperature of gas and wall. The radiation coefficient for this mean temperature is to be read from Figure 7 or Figure 8, for $(T_1 - T_2) = 0$. This must then be multiplied by the emissivity as determined from the gas radiation curves and by the temperature difference. A slight deduction must now be made—*i.e.*, 20 per cent for a mean temperature of 2000 degrees F., 10 per cent for a mean temperature of 1500 degrees F., falling to zero for mean temperatures of 1000 degrees F. or less.

To give some idea of the relative importance of convection and gas radiation, the coefficients of convection and of gas radiation for gas of four different compositions flowing at different velocities through tubes of different diameters have been plotted in Figures 12, 13, and 14 for mean temperatures of 2000 degrees F., 1000 degrees F., and 500 degrees F. respectively. The gas in case (1) contains 16 per cent of carbon dioxide and 19 per cent of water vapor; in case (2) 19 per cent of carbon dioxide and 1 per cent of water vapor; in case (3) 6½ per cent of carbon dioxide and 18 per cent of water vapor; and in case (4) 12 per cent of carbon dioxide and 3 per cent of water vapor.

It will be seen that as the diameter of the tube, and the temperature of the gas, increase, gas radiation becomes more and more important compared with convection. Thus for a tube diameter of 12 inches and a mean temperature of 2000 degrees F. the radiation from mixtures (1) and (3) is equivalent to convection for about 60 feet per sec. (N.T.P.), and for mixtures (2) and(4) about 35 feet per sec. For a tube diameter of 1 inch and a mean temperature of 500 degrees F. gas radiation for all four mixtures is negligible compared with convection for any rate of flow above 10 feet per sec.

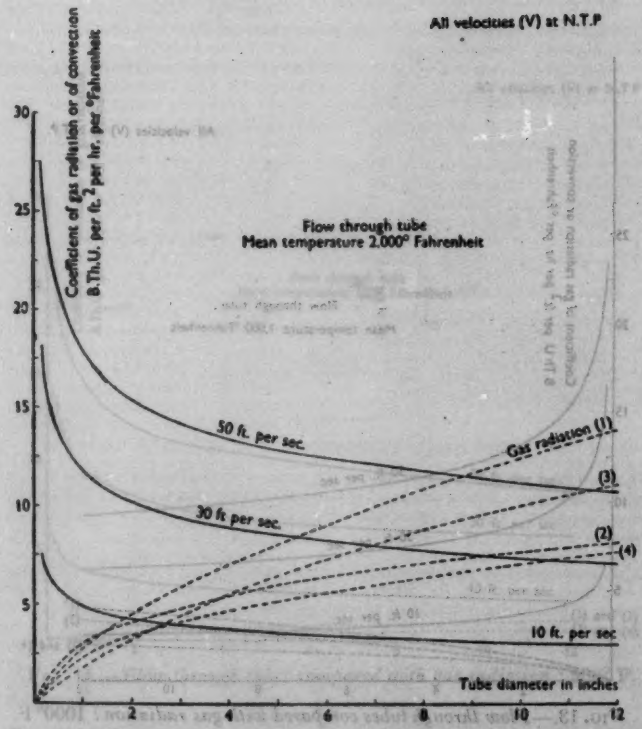


FIG. 12.—*Flow through tubes compared with gas radiation : 2000° F.*

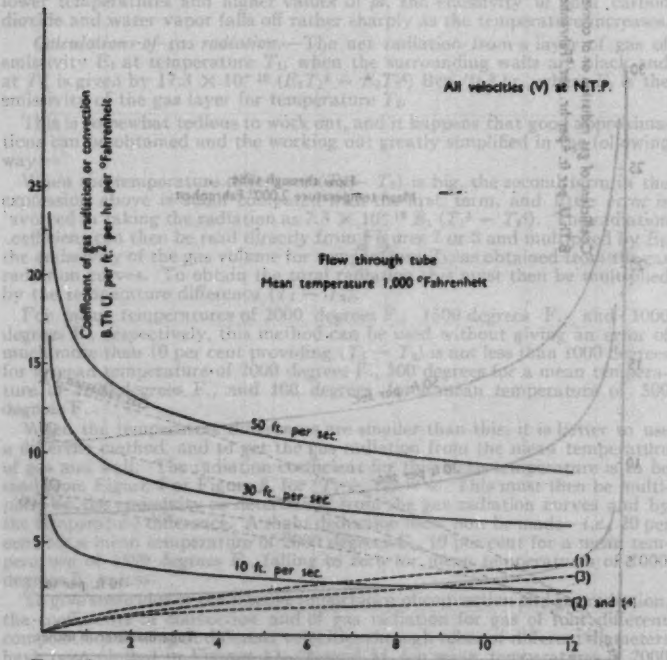


FIG. 13.—*Flow through tubes compared with gas radiation: 1000° F.*

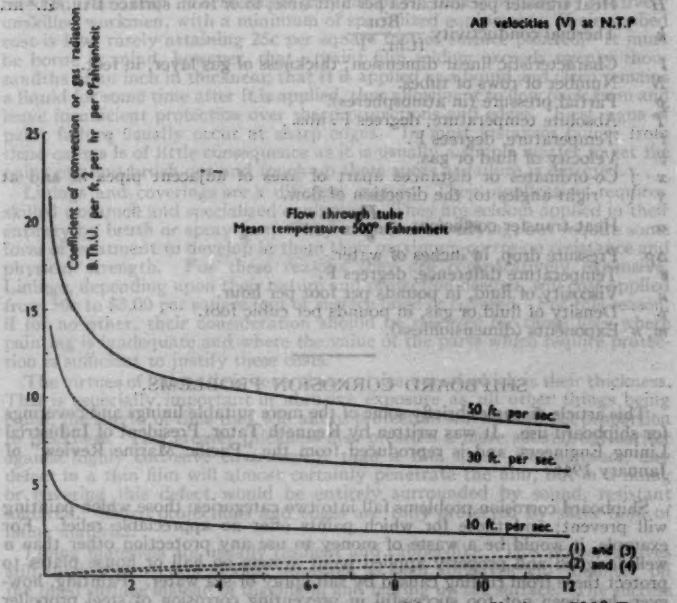


FIG. 14.—*Flow through tubes compared with gas radiation : 500° F.*

The authors are very much indebted to Mr. D. W. Rudorff, who most kindly supplied them with English abstracts of the two Russian papers on tube banks mentioned in the text.

Appendix—List of Symbols.

C	A constant (dimensionless).
C_H	Factor, depending upon tube arrangement, affecting heat transfer.
C_f	Coefficient, depending upon tube arrangement, affecting pressure drop.
c	Specific heat at constant pressure of fluid $\frac{\text{Btu.}}{\text{lb. °F.}}$
d	Diameter of pipe, in feet (unless otherwise stated).
E	Emissivity (dimensionless).
H	Heat transfer per unit area per unit time, to or from surface Btu./ft.^{2} hr.
k	Thermal conductivity $\frac{\text{Btu.}}{\text{ft.hr. °F.}}$
l	Characteristic linear dimension; thickness of gas layer, in feet.
N	Number of rows of tubes.
p	Partial pressure (in atmospheres).
T	Absolute temperature, degrees F. abs.
t	Temperature, degrees F.
v	Velocity of fluid or gas.
x, y	Co-ordinates or distances apart of axes of adjacent pipes in and at right-angles to, the direction of flow.
α	Heat transfer coefficient $= \frac{H}{\theta}$.
Δp	Pressure drop, in inches of water.
θ	Temperature difference, degrees F.
μ	Viscosity of fluid, in pounds per foot per hour.
ρ	Density of fluid or gas, in pounds per cubic foot.
m, n	Exponents (dimensionless).

SHIPBOARD CORROSION PROBLEMS.

This article discusses briefly some of the more suitable linings and coverings for shipboard use. It was written by Kenneth Tator, President of Industrial Lining Engineers, and is reproduced from the "Pacific Marine Review" of January 1946.

Shipboard corrosion problems fall into two categories: those which painting will prevent; and those for which paints offer no appreciable relief. For example, it would be a waste of money to use any protection other than a well-designed and properly applied paint system on hall or house plates to protect these from rusting caused by salt spray or sea water. Painting, however, has been not too successful in preventing corrosion of steel propeller shafts driving bronze wheels. For their protection a heavy, resilient synthetic rubber has given the best protection. It is of this latter class of corrosion protection that this article deals, that of linings or coverings.

Linings and coverings with but few exceptions are characterized by their thickness, normally from 3½ to ¼ of an inch. They are usually resilient, rubber-like materials, selected for corrosion and abrasion resistance. No one lining material will be a universal panacea for all corrosion problems, but among the lining materials commercially available there is generally at least one which will solve any specific problem. Among those materials available, and in common use for lining or covering, are rubber and the many types of synthetic rubbers, and plastics such as the Bakelites, vinyls, polyethlene, polystrene, vinylidene, chlorides and others. Unfortunately for many purposes these lining materials are seldom known by their true names, and their identity is obscured by non-informative trade names. The writer recently visited the engineering division of a well-known organization which was then

attempting the solution of a serious corrosion problem. Those men had invested a considerable amount of time and money in exhaustively testing eight lining samples, known only to them by trade-name, which had been recommended to them for the purpose. Of these eight test pieces, six were of identical material, differing only in trade-name, minor composition, and integrity of the manufacturer—an unnecessary duplication of investment, especially in view of the fact that this material proved inferior to other materials available. Such a situation can be avoided by asking the supplier the true nature of this material, or by enlisting the advice of men able to distinguish between the available trade-names.

Linings and coverings cannot economically and should not replace painting. Paint systems are adequate for the more common corrosion problems encountered on board ship. Furthermore they can be effectively applied by relatively unskilled workmen, with a minimum of specialized equipment. Their applied cost is low, rarely attaining 25c per square foot of surface painted. It must be borne in mind, however, that a paint film seldom exceeds twenty thousandths of an inch in thickness; that it is applied as a liquid and often remains a liquid for some time after it is applied, thus allowing it to flow back from and leave insufficient protection over sharp projections and edges. First signs of paint failure usually occur at sharp edges. In most instances failure from these causes is of little consequence as it is usually a simple matter to get the paint can and brush out and touch up these spots as failure is detected.

Linings and coverings are a different matter. Their application requires skilled workmen and specialized equipment. They are seldom applied in their entirety by brush or spray gun. They are never air-drying, but require some form of treatment to develop in them their maximum corrosion resistance and physical strength. For these reasons they are comparatively expensive. Linings, depending upon their nature and protection desired, will cost applied from 50c to $3.00 per square foot of surface lined or covered. For this reason, if for no other, their consideration should be reserved for those uses where painting is inadequate and where the value of the parts which require protection is sufficient to justify these costs.

The virtues of linings lie in several properties, one of which is their thickness. This is especially important in abrasive exposure as, all other things being equal, the length of time they will afford protection will be in direct proportion to thickness. This greater thickness also presents a more substantial barrier against highly corrosive environment than a thin film. Furthermore, any defect in a thin film will almost certainly penetrate the film, but in a lining or covering this defect would be entirely surrounded by sound, resistant material. Sharp projections and edges are fully protected by sheer bulk of lining material.

Lining materials are usually resilient and rubber-like. This property gives still further protection against abrasion, as such abrasives will "bounce" off the lined surface instead of digging in and tearing up the surface. The success of the rubber-lined shaft bearings is evidence of this, to say nothing of the wearing qualities of automobile tires .Resilience is also of advantage in maintaining a protective barrier over "working" rivet heads on lap seams. The material at these points will stretch and "work" with the steel instead of cracking under the shearing action.

Linings and coverings are usually treated after application to impart to them their maximum resistance and strength. This "set," "cure" or vulcanization is variously accomplished by heat, pressure vapor or gas reaction. Special portable equipment is required. This operation after application insures maximum adhesion to the steel and a stress-free lining.

Lining and covering is in general accomplished by four different methods, depending upon the material employed or the result desired. They may be applied to specially prepared surfaces by pressure guns, by trowel, and by molding, and those so applied are characterized by being continuous and seamless. Sheet linings necessarily have seams but are usually smoother, of more uniform appearance and of uniform thickness.

Repairability of a lining is of paramount importance to shipowners. For protection as costly as lining or covering it is not economically desirable to replace a lining which has sustained damage to a small part of its total area. All linings cannot be repaired, but those which are classed as "thermoplastic" can be repaired with a minimum of time and expense, whereas with the "thermosetting" materials a repair is a major undertaking yielding a resulting lining which is often a compromise in quality. Hence in the summary at the end of this article the various lining materials will be classified according to their type.

Linings serve three types of function: they protect marine equipment from severe corrosion action of sea water, salt spray, or the cargo; they protect equipment from the abrasive action of silt, hard fuels, or solid bulk shipments; and they protect cargoes from undesirable contamination by iron or rust from contact with the bulkheads in the holds.

In the following the qualifications and uses of some of the principal lining and covering materials will be summarized:

Natural Rubber.

Thermosetting. Best abrasion resistance. Excellent resistance to acid and alkaline conditions. Should not be used where lubrication oil or fuel oil will come in contact with it. Not suitable for oily shipments. Used to line battery compartments.

Synthetic Rubber—GR-S Type.

Same general characteristics as natural rubber, but harder, hence with somewhat lessened abrasion resistance.

Synthetic Rubber—Buna N Type.

Thermosetting. Good abrasion resistance. Excellent resistance to lubricating and fuel oils and to petroleum products. Excellent for vegetable oils and oily loadings.

Neoprene.

Thermosetting. Excellent abrasion resistance. Excellent resistance to lubrication and fuel oils and to petroleum products except aviation gasoline, due to aromatics. Excellent for vegetable oils and oily ladings.

Thiokol.

Thermosetting, although latex types readily repaired. Poor abrasion resistance. Has tendency to flow under pressure. Best resistance to petroleum products, including aviation gasoline, and used to line steel and concrete tankers and tank barges. Used to cover propeller shafts and streets. Not recommended for temperatures above 120 degrees F.

Vinyls.

Thermoplastic. Good abrasion resistance. Excellent resistance to alkaline and acid conditions, petroleum products, fats and oils.

Polyethylene.

Thermoplastic. Fair abrasion resistance. One of best for acid and alkali resistance. Softened by contact with petroleum oils.

Bakelites

Thermosetting. Poor abrasion resistance. Excellent acid resistance. Poor alkali resistance. A glass-smooth thin lining with relatively good heat transfer properties, used to cover and line pumps, steel condenser tubes, pipes and fittings. Will withstand temperatures in excess of 350 degrees F.

POLYSTYRENE.

Thermoplastic. Excellent acid and alkali resistance. Poor resistance to petroleum products.

VINYLIDENE CHLORIDE (SARON).

Thermoplastic. Good abrasion resistant to salt water and spray. Are not recommended for temperatures continuously above 200 degrees F.

SOME FUNDAMENTALS IN ALL-WELDED SHIP CONSTRUCTION.

This paper by Milton Forman, Welding Engineer, Ingalls Shipbuilding Corporation, Pascagoula, Mississippi, presents some of the practical aspects in all-welded ship construction. It is reproduced from the "Welding Journal" of October 1945.

The Emergency Shipbuilding Program is drawing to a close and the shipowners and shipbuilders are planning the postwar passenger and cargo vessels which will be plying the seas.

At this time, the experiences, both good and bad, gained during intensive wartime construction and service should be carefully evaluated in order to determine the best and most economical methods to be used for the future. The competition during this coming period will be very keen, and as a result the quality of workmanship should improve considerably and the cost should be greatly reduced.

When the war began, the tasks and quotas set for the shipbuilding industry seemed beyond realization. However, new yards sprang up all over the country, old yards expanded manifold, and the quotas were fulfilled and surpassed. This unprecedented expansion of the shipbuilding industry, coupled with the demands of the Armed Forces, left the shipyards with inadequate supervision and a large proportion of unskilled workmen. In addition to this, the urgent demand that the ships be delivered *now*, meant that quality of workmanship was sacrificed to quantity production.

Is there any wonder, therefore, that fractures developed in some ships prior to and during service? The most dramatic example of these failures was the breaking in two of the S.S. *Schenectady*.[8]

SHIP FAILURES.

An analysis of the figures presented on June 3, 1944, in the report[9] of the Board of Investigation designated by the Secretary of the Navy shows that—

From a total of 2993 ships, 95 or 3.2 per cent developed potentially serious failures.

20 vessels or 0.67 of 1 per cent suffered complete loss of the strength deck.

5 or 0.17 of 1 per cent broke in two.

CAUSE OF FAILURES.

A report delivered before the House of Representatives[1] on June 20, 1944, reported the following:

"The causes for plate fractures may be summarized as—

1. Internal or locked-up stresses resulting from welding and the failure to observe proper welding sequence.
2. Poor quality of welding workmanship and inadequate supervision and inspection.
3. The characteristic of steel known as notch sensitivity.
4. Unity of welded structures resulting in no crack stoppers.
5. Deficiency in details of design.
6. Low temperature and temperature changes.
7. Results of ship operation practices required by the exigencies of the war.
8. Inexperienced personnel."

As a result of the foregoing, regulatory bodies required[3] that improvements be made in design and that crack arrestors, in the form of riveted gunwale bars and riveted deck straps, be added to the ships in service and the ships on the Ways.

Crack Arrestors.

The above requirements sought to eliminate fractures due to design and to stop cracks once they had started. There is no doubt that this was necessary as an immediate measure to alleviate the situation. However, the blanket application of this requirement assumes that fractures are inevitable in a welded structure, and that these fractures inevitably propagate with the resultant loss of major strength members.

It seems to me that although the riveted gunwale bar could be justified for many ships built in the haste of wartime construction, it is basically unsound to insist on its use for all ships and especially for vessels built for peacetime operation under normal building conditions.

It is the contention of The Ingalls Shipbuilding Corp. that all-welded ships have, can and will be built to be completely free of fractures. The fact that 2561 of 2993 ships[9] built during adverse wartime conditions are successfully operating under severe wartime service (as of June 1944) with no indication of fracture, is ample proof of this. Also, the fact that welded hulls of the C-3 and C-1 type have developed comparatively less fractures than the Liberty ships further substantiates this thought.

As of June 1944, of 1995 Liberty Ships analyzed,[1] 9.47 per cent developed either Class 1 or Class 2 fractures.

Of 73, C-3 Hulls, 2 or 2.74 per cent developed these fractures.

Of 122, C-1 Hulls, 2 or 1.62 per cent developed the same.

It is therefore obvious that a ship of superior design to the Liberty ship, despite the faults of wartime construction, has a much lower frequency of fracture.

Statistics, of course, do not show the entire picture. Therefore, let us carefully analyze the causes and see to what extent they can be controlled and eradicated.

Residual Stresses.

One of the characteristics of welding is that high longitudinal stresses are developed in the weld and immediately adjacent to the weld. These stresses vary with the thickness of the plate and are in the neighborhood of the yield point of the weld metal.

Considerable research has been done to determine whether the presence of these stresses reduce the strength of the welded structure.

A Committee of the Welding Research Council in a discussion[3] of the "Weld Stress Problem" states the following:

> "Experimentally it has not been shown in a laboratory that these residual stresses cause a structure to behave a great deal differently than one without them."

The above statement is limited by the following:

> . . . "practical experience indicates that this general statement cannot be carried over to thick materials where considerable triaxiality is involved. This is the object of the Structural Steel Program of the Bureau of Standards. . . ."

The results of the pilot test of Box Girder No. 1, tested at the National Bureau of Standards as part of the above program, are now available. (See Figures 8-11.) They also indicate that the high residual stresses, deliberately welded into this 9-ton girder because of a very abusive sequence,[4] had little, if any, effect on the ultimate strength. Despite the presence of a notch, virtually the entire calculated strength was utilized before the girder failed.

Mr. Leon C. Bibber, in his paper[5] presented to the Annual Meeting of the Society of Naval Architects and Marine Engineers, comes to the following conclusion:

"... good strength and elongation can be obtained from longitudinally welded joints of heavy plates in both angle type and flat plate although considerably less elongation occurs in the tee type when automatically welded with the deck in the horizontal plane."

An investigation[8] carried out under the auspices of the Ukrainian Academy of Sciences, Institute of Electric Welding, came to the following conclusion:

"In 17 out of 19 tests which were performed, the strength of the base metal was not found to be reduced by the shrinkage stresses when the construction was subjected to static and vibration tests."

As a result of these and other investigations, there seems little doubt that residual stresses contribute little, if anything, toward reducing the strength of welded structures.

In addition to the above, methods have been found of reducing and controlling these residual stresses. The Low Temperature Stress Relief Method developed jointly by Sun Shipbuilding Co. and The Linde Air Products has been proved to reduce the peak values of these stresses to a very great degree. Peening the weld metal and two inches of the adjacent parent metal has also proved successful in this respect.

Reaction Stresses.

Reaction stresses are those caused by the external restraint of members. If temperature changes or welding shrinkage takes place in a section under external restraint, these reaction stresses develop.

The Subcommittee on Hull Construction in its tentative report,[7] "Structural Failures in Welded Ship Construction," states:

"If there is some focal point of high concentration of stress due to geometrical irregularities or poor workmanship, a crack is likely to start at this point and, if the reaction stresses are high enough, may extend for a considerable distance."

To cite an example from experience, which in my opinion shows the role played by reaction stresses in developing a structural failure. (See Figure 1.) Note that here we have most of the elements of a major ship failure.

1. A completely brittle failure.
2. Comparatively low temperature, 20 degrees to 45 degrees F.
3. Twenty-five degrees change in temperature within 24 hours.
4. Excessive flame shrinking taking place and providing additional reaction stress and energy to propagate the fracture.
5. Disregard of good welding practice by crossing an unwelded butt in hatch coaming and developing an initial small crack and sharp notch.

Our experience shows that although reaction stresses cannot be completely eliminated, since there is always some kind of external restraint present, they can be satisfactorily controlled. This is the reason why we developed a complete and thorough fitting and welding sequence at the Ingalls Shipyard. (See paper[10] written by author in the April 1945 issue of "The Welding Journal.") A well-planned and carefully controlled fitting and welding sequence can control these reaction stresses. Special measures, including peening of close in, final welds, must be resorted to, wherever there is excessive restraint.

Stress Risers and Stress Concentrations.

Stress risers are the result of abrupt changes in section in design, or notch effects which arise from defective welding, irregular burning, etc. These prevent the smooth distribution and transmission of stresses.

The Committee of the Welding Research Council in a statement[3] on "Weld Stress Problem" declares:

"There seems to be general agreement that this one factor (stress risers) overshadows all others, and in combination with low-temperature notch sensitive steels and impact loading accounts for most of the trouble."

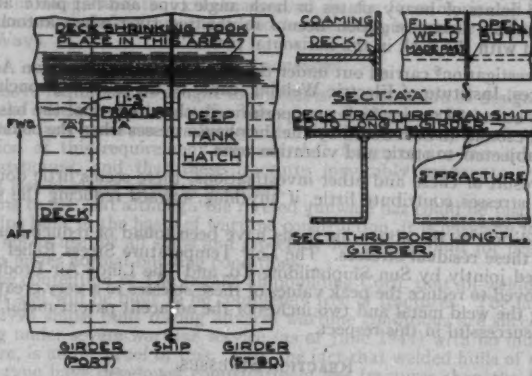


Fig. 1—Note That Excessive Flame Shrinking and 25° Change in Temperature Provided the Reaction Stresses and Energy to Propagate Fracture. A Small Crack and Sharp Notch Developed in Deck Plating When Fillet Weld Crossed the Unwelded Butt of Coaming.

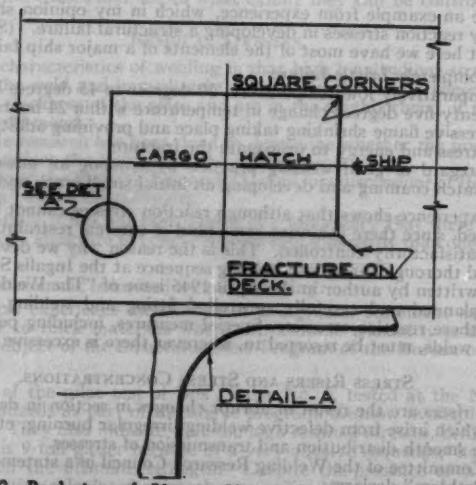


Fig. 2—Re-design of Abrupt Changes in Section at Hatch Corners, Attachments to Sheer Strake, etc., Has Already Decreased Fractures at These Locations.

A careful investigation of the fractures which have occurred invariably leads us to a stress riser as the source. Since this truth stares us in the face more sharply every day, it means that the shipbuilder must pay *major attention* to eliminating these sources of fractures, if he is to produce welded ships free of failures.

A thorough analysis of past fractures, especially the more serious ones, shows that they invariably start at one of six specific locations. These locations are:

1. Square hatch corners.
2. Notch or abrupt change in section at the upper edge of the sheer strake.
3. Faulty weld at gunwale connection.
4. Faulty weld at end of Main Deck erection butts.
5. Faulty weld at bulwark and continuity at bulwark butts to main structure.
6. Faulty weld in bilge keel and continuity at bilge keel butts to bilge strake.

It is obvious therefore that each individual fracture has as its starting point a stress riser in the form of poor design or faulty workmanship. As a result of requirements[2] on the part of regulatory bodies, most of the design stress risers at the above crucial locations have been eliminated. The hatch corners have been reinforced and rounded. (See Figure 2.) The attachments at the sheer strake have been either eliminated or redesigned to allow for a smooth transmission of stresses. The bilge keel and bulwarks have been improved and no longer allow continuity in way of welded butt joints. (See Figures 3 and 4.)

The above-cited measures alone have reduced the fractures in these locations to a very great extent. More steps can and are being taken to further improve the design of our ships. In order to guarantee that no detail of design is overlooked, the Ingalls Shipbuilding Corp. is carfully reviewing all plans and is making alterations where they are justified.

Workmanship.

Given a satisfactory design, the most crucial factor in building ships which will be free of fractures, is painstaking workmanship. Although it is understandable, it is quite unfortunate that this was lost sight of, to some extent, during the intense effort to fulfill the demands of the shipbuilding program. The Ingalls Shipbuilding Corp. is rather proud that it laid major emphasis on good workmanship all the way through this emergency program.

The problem of building fine all-welded ships is not something which can be discussed and resolved in the abstract. These vessels must be built by a designated number of men. If they do not understand the nature of welding and if they do not intelligently use their tools, the product will be inferior.

There has been a tendency on the part of some people to say that a ship is so large and there is so much welding on it that it is impossible to ensure that all the welding is sound. The fractures which tend to endanger the 100 per cent welded ship are not located all over the ship. They are localized to six specific locations. When the problem is approached from this point of view, it is not overwhelming. It therefore becomes a relatively simple, but very important, job to guarantee the quality of work at these points.

There are no deep dark secrets about these danger areas; therefore, the builder must make arrangements to take special precautions at these locations.

Careful preparation and welding are required at each erection joint of the Main Deck. The starting and ending points of these welds should be cleaned out in way of the welding to the shell and hatch coamings and rewelded. (See Figure 5.) These welds should be peened in order to minimize root cracks. Back gouging should be carefully carried to sound metal. (See Figure 6.) If the above precautions are followed there is little likelihood of stress risers due to faulty welds.

The upper edge of the sheer strake has already been cleared of abrupt changes in design. It will therefore be a comparatively small job to inspect the same for notches caused by careless burning, etc.

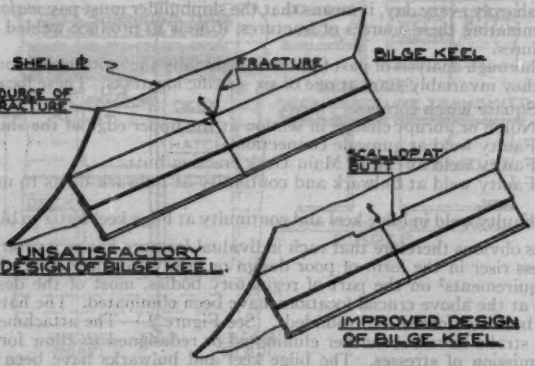


Fig. 3—Re-design and Breaking Continuity at Butt Welds, Where They Attach to Shell, Eliminates Possibility of Fracture Propagating Into Shell Plate.

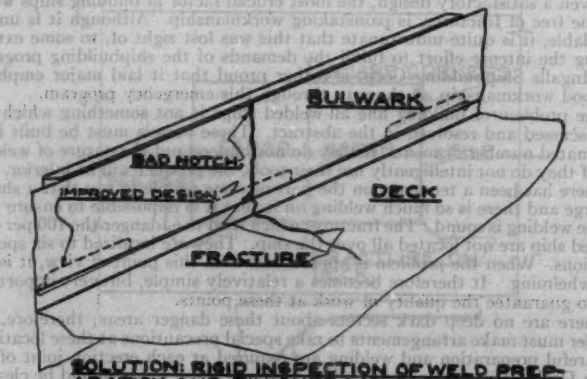


Fig. 4—Re-design and Breaking Continuity at Butt Welds, Where They Attach to Shell, Eliminates Possibility of Fracture Propagating Into Shell Plate.

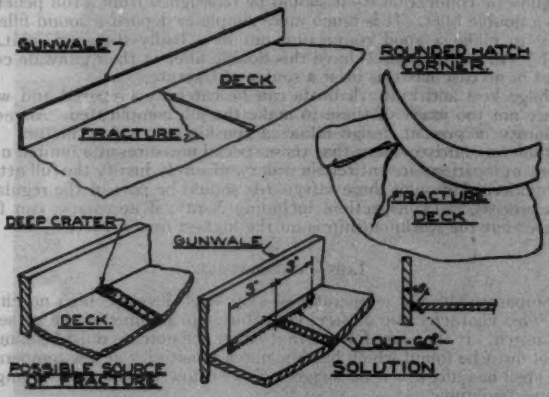


Fig. 5—Special Precautions Which Insure Sound Welding at Ends of Erection Butts in Main Deck, Eliminates These Locations as Crack Starters.

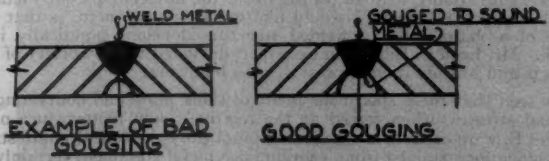


Fig. 6—Careful Back Gouging Eliminates Cracks from Forming in Welds.

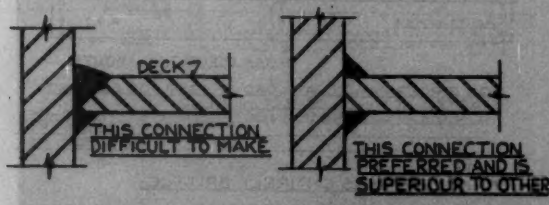


Fig. 7—A Good Full Penetration Weld, with Only One Side Beveled, Is Difficult to Deposit. Double Fillet Weld Is Preferable at Gunwale Connection.

The gunwale connection itself should be redesigned from a full penetration weld to a double fillet. It is much more simple to deposit a sound fillet weld than try to make a good connection out of a badly designed joint. (See Figure 7.) All Ingalls vessels have this double fillet at their gunwale connection, and in no case has this been a source of fracture.

The bilge keel and bulwark butts can be carefully prepared and welded. There are not too many of these to make the job complicated. Already the discontinuity in present design allows a considerable safety factor.

It is therefore fairly evident that these special measures at a limited number of important locations are entirely in order and surely justify the full attention of the builder. Although these safeguards should be part of the regular production process, rigid inspection, including X-ray, if necessary, can further guarantee that the workmanship is on the highest quality.

Low Temperature.

At comparatively low temperatures, ship steel develops high notch sensitivity. This characteristic of steel contributes to failures in the presence of a sharp notch. It therefore follows that either the notches must be eliminated or a steel must be found which has low notch sensitivity at low temperatures. Such a steel has already been suggested, with low carbon, high manganese and some aluminum.

It should be kept in mind that notches in design or workmanship are still undesirable even for a steel of low notch sensitivity. Therefore, we again end up with the need to eliminate stress risers and stress concentrations. It is my opinion that these have and can be eliminated where proper control has been exercised.

It ought to be mentioned at this time that investigations have shown that the notch sensitivity of the weld metal is not greater than that of the base metal. It is a rather common observation that those fractures that do start in the weld invariably tend to propagate in the adjacent parent metal.

Another important point, I would like to call attention to, is that in the absence of a sharp notch, a welded structure develops practically its full strength. Mr. Leon C. Bibber, in his paper[6] delivered to the Society of Naval Architects and Marine Engineers, states the following:

> "It is seen that these specimens made of thick plate and containing these residual stresses, when tested at the relatively low temperature of +20 degrees F. were capable of developing practically the full ultimate strength and elongation attained from a virgin base metal specimen, certainly more strength and elongation than the joint could be called upon to develop in a ship."

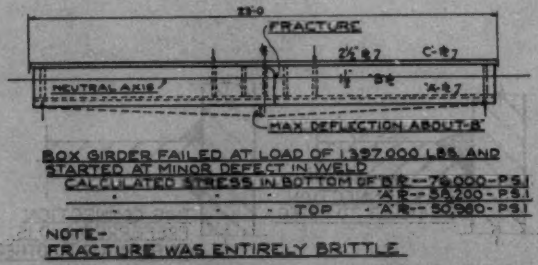


Fig. 8—Data on Box Girder No. 1. Practically Full Strength of Girder Utilized Before Fracture Occurred

Fig. 9—Box Girder No. 1 Ready to Be Tested at National Bureau of Standards, Wash., D. C. Box Girder No. 1 Was Built at Ingalls Shipbuilding Corp. Five More Will Be Built as Part of the Same Program.

Fig. 10—Detail of Fracture After Completion of Test, Box Girder No. 1.

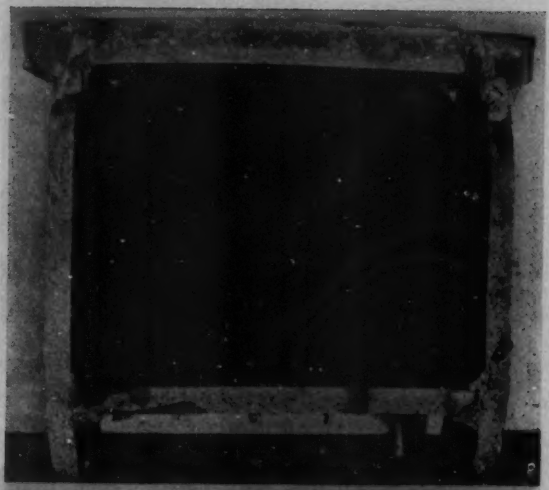


Fig. 11—Cross-sectional View Showing Brittle Fracture. Note Defect in Weld at Lower Left Hand.

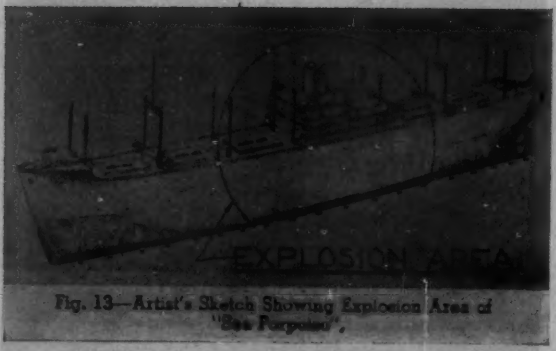


Fig. 13—Artist's Sketch Showing Explosion Area of "Sea Porpoise".

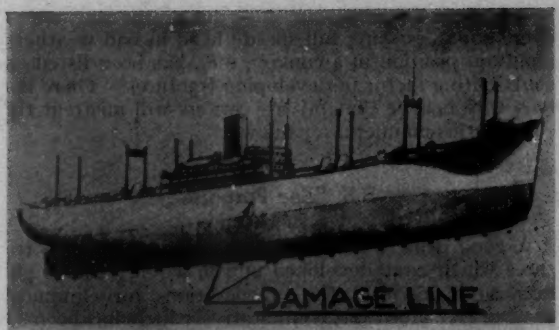
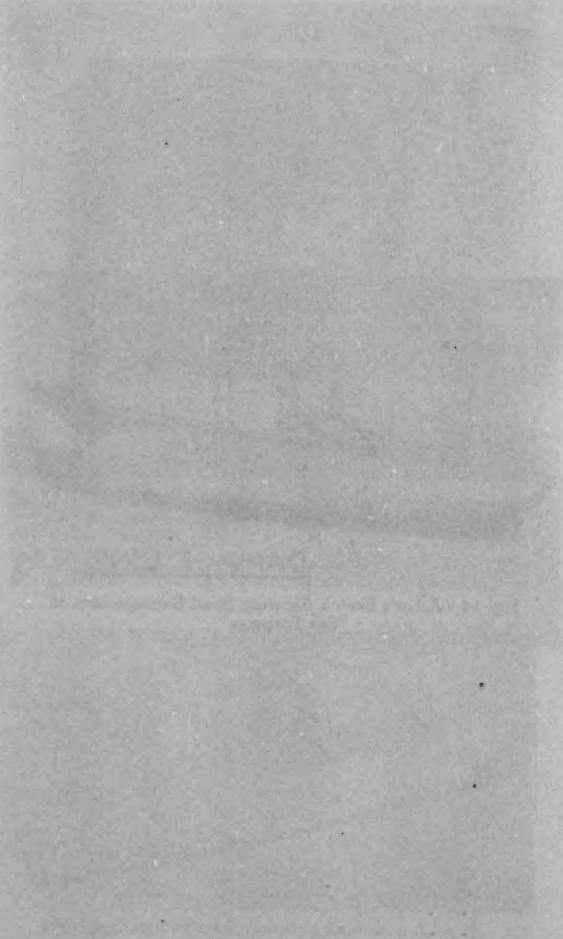


Fig. 14—Artist's Sketch Showing Shell Damage Line of "Sea Porpoise"



I also expect that the testing of Box Girder No. 2 at the National Bureau of Standards at −40 degrees F. will show similar results, in the absence of a notch, and despite the presence of multi-directional constraint.

Rigidity.

In examining the fractures which have occurred, the fact that the failures were brittle in character and that no or little plastic flow took place, stands out. To a certain extent this is attributed to the presence of multi-directional constraint characteristic of a ship's design. Again referring to the test of Box Girder No. 1, at the National Bureau of Standards, we see that despite the severe constraint, the brittle fracture and the maximum of 2.1 per cent reduction in thickness at the fracture, the girder did not fail until practically its entire strength was utilized. (See Figures 8-11.) This failure took place after about 8 inches deflection from the neutral axis, and about 6 inches permanent "set."

It does not seem, therefore, that the great rigidity of this 9-ton girder, built from 2½-inch and 1½-inch plate, decreased the over-all strength under a test of static loading. There is no doubt that the design did contribute toward developing a brittle type of failure.

If this test can be taken for an indication, it seems to me that the rigidity or multi-directional constraint existent in welded ships does not reduce their ultimate strength and therefore make them more susceptible to failure. We do know that the normal "working," hogging and sagging, of the all-welded ship is not hampered by its welded joints.

There is no question that much more can be done to further investigate this problem.

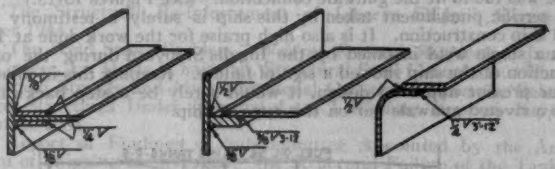


Fig. 12—Typical Designs for Crack Stoppers. These Will Be Tested as Part of Program at National Bureau of Standards.

Absence of Crack Stoppers in All-Welded Ships.

It is true that all-welded ships today do not have crack stoppers. However, given a ship which has been carefully constructed, it is the contention of the Ingalls Shipbuilding Corp. that this requirement is unnecessary. We feel that the real problem is to stop the crack from starting. If all hands concentrate on improving design and achieving superior workmanship, the theory of supplying crack stoppers becomes superfluous.

Despite the foregoing, future tests have been planned to investigate the possibilities of developing a welded type of crack stopper. These tests are part of the program[4] conducted at the National Bureau of Standards. (See Figure 12.)

We should also keep in mind that despite the low notch toughness of ship steel, a very low proportion of ship fractures have propagated from one strength member to another.

Wartime Operating Conditions.

The abuse taken by our ships during the war, such as overloading, pushing full speed ahead in bad weather to maintain position in a convoy, etc., has been listed as a contributing factor in developing fractures. There is no

reason to believe that private owners will mistreat their ships in this manner after the war.

S.S. "Sea Porpoise."

A good deal of attention has been paid to the fractures which have developed and in a sense this is good because it has laid the preconditions for eliminating the causes. However, comparatively little has been said of the terrific punishment taken by some of the all-welded ships. Statistics do show that of the all-welded ships built, 85.6 per cent have developed no sign of fracture as of June 1944, despite the shortcomings of wartime shipbuilding and ship operation.

At this point, I would like to call attention to a ship, S.S. *Sea Porpoise*, built by Ingalls as a C3-S-A2 vessel, and converted to an Army transport. This ship underwent an experience, the survival of which I believe can be attributed to the fact that it was of welded construction. A severe underwater explosion took place beneath the bottom at midships, causing a tremendous upward pressure, bodily lifting the vessel from 2 to 3 feet, according to Lieutenant Commander E. V. Williams, then first mate and now master of the vessel.

Although buckling took place on the shell between two frames on the starboard side, extending from the flat keel to the sheer strake, not a single leak developed in the weld or plating. A small leak did finally develop in the flat bottom at the longitudinal girder in the cofferdam when the ship was lifted out of the water in drydock. As a result of the explosion, the severe hogging action did develop three small fractures in the shelter deck at three square hatch corners. Other structural, piping and machinery damage was sustained below the shelter deck, but these did not affect the basic hull structure. No damage was found at the gunwale connection. (See Figures 13-15.)

The terrific punishment taken by this ship is surely a testimony to all-welded ship construction. It is also high praise for the work done at Ingalls for not a single weld installed by the Ingalls Shipyard during the original construction of the ship showed a sign of failure. Keeping this in mind, and with our present improved design, it would surely be a step backwards to require a riveted gunwale bar on this type of ship.

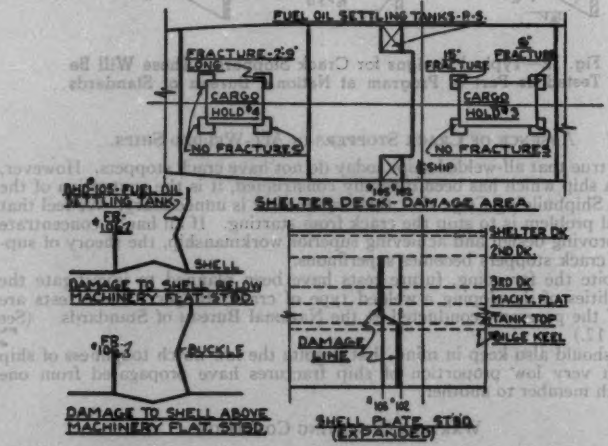


Fig. 15—Details Showing Fractures Developed as a Result of Explosion.

Conclusion.

I am not offering this paper with the thought that the last words have been said concerning the building of 100 per cent welded ships. There are still many problems to be solved, and there is much research work to be done. However, it is my firm belief that the theory of completely welding large structures such as ships, should not be discarded at this time.

Peacetime standards and highly skilled workmen will remain in the shipyards which will continue operating. Added to this, careful planning and adequate supervision will undoubtedly allow us to overcome the faults of hasty wartime construction. We have and will continue to build cheaper, faster and stronger welded ships.

I would like to conclude with some pertinent remarks made by the Subcommittee on Hull Construction in its report[7] on structural failures:

"Probably the greatest source of trouble under present conditions is overconfidence on the part of production workers and supervision who have violated rules of procedure in the past without apparent trouble and who fail to realize that the margin of safety may be entirely destroyed by a combination of circumstances in another case.

"Properly informed and adequate supervision, not only in welding but in the departments preparing the materials for welding, is a necessary factor in engineering control."

References.

1. "Investigation of Plate Fractures on Welded Ships," *House of Representatives Report No. 1685*, June 20, 1944.

2. "The Structural Re-inforcement of Liberty Ships," *Marine News*, October 1944.

3. "The Weld Stress Problem," *Welding Research Supplement*, June 1945.

4. Grover, La Motte, Chairman, Structural Steel Committee, "The Effect of Residual Stresses and Multi-directional Constraint Upon the Behavior of Welded Structures Under External Load," *Welding Research Supplement*, December 1944.

5. "Report of Findings of Subcommittee Appointed by the American Bureau of Shipping to Investigate the Structural Failure of the Tanker S.S. *Schenectady*."

6. Bibber, Leon C., "A Study of the Tensile Properties of Heavy Longitudinally Welded Plate Specimens Simulating Deck and Shell Joints." Presented to Society of Naval Architects and Marine Engineers, November 1944.

7. "Structural Failures in Welded Ship Construction." Report of Subcommittee on Hull Construction. Approved by the Board of Directors of the American Welding Society, April 1944.

8. "Behavior of Residual Stresses Under External Load and Their Effect on the Strength of Welded Structures." Investigation carried out under the auspices of the Ukrainian Academy of Sciences, Institute of Electric Welding. Printed in *Welding Research Supplement*, September 1944.

9. "Interim Report of Board of Investigation Convened by Order of the Secretary of the Navy to Inquire Into the Design and Methods of Construction of Welded Steel Merchant Vessels," *Marine News*, October 1944.

10. Forman, Milton, "Organized Fitting and Welding in Shipbuilding," The Welding Journal, April 1945.

SECOND INTERIM REPORT OF THE BOARD TO INVESTIGATE THE DESIGN AND METHODS OF CONSTRUCTION OF WELDED STEEL MERCHANT VESSELS — EXHIBIT IV — SURVEY OF RESEARCH PROJECTS, APRIL 1, 1945.

"This portion of the subject report is particularly interesting and valuable since it summarizes the theoretical considerations to date."

I. Introduction.

As a result of structural failures of welded ships numerous research investigations were started at the instigation of the Board convened April 20, 1943, by the Secretary of the Navy to investigate the design and methods of construction of welded steel merchant vessels, and by other governmental and private agencies to determine the relative importance of the various factors which at that time were thought to contribute to those failures.

The research investigations which have been undertaken to determine the cause, or causes, of failure in welded steel ships may be classified as follows:

1. Design.
2. Materials.
3. Fabrication.

The Research Advisory Committee, appointed to take cognizance of, coordinate and evaluate all research work which is considered to have a bearing on the problem, hereby attempts for the first time to evaluate the results of these investigations.

In presenting this summary, the Committee desires to draw attention to the fact that the majority of the results obtained to date deal with the subject of fabrication and in particular with that of residual welding stresses. This emphasis on residual welding stresses reflects the importance which was attached to this subject by the majority of the technical personnel in the industry, when the research program was initiated, whereas the full significance of the type of fracture encountered in ship failures was not recognized until recently. The studies now under way on materials have not proceeded to the point where final conclusions based on complete test data may be presented, even though during the last six months greater emphasis has been placed on the investigations of materials.

II. Discussion of Results.

1. Design.—Full-scale tests on welded ships have corroborated earlier experiments in riveted ships and confirmed the validity of the basic analytical methods in calculating the stresses in the main hull girder. Application of this method to present welded ships indicates a general level of stresses comparable to those of riveted ships. There are several research projects which have contributed significantly to design details. These projects have investigated stress distributions on board ship during loading and at sea, around such structural discontinuities as hatch corners, and much experimental data are at present being analyzed. In one investigation a strain concentration of 7 was measured at sea. This unexpectedly high value is of great significance and warrants considerable additional research.

2. Materials.—A substantial random selection consisting of 257 samples of steel was collected from the stock and scrap piles of shipyards constructing merchant vessels; 1028 tensile tests from these samples indicated that practically all of this steel complied with existing specifications for physical properties.

Notched-bar impact tests on rimmed, semikilled and fully killed grades of ship steel have shown that the transition from ductile to brittle behavior occurs at a relatively low temperature for fully killed steel, at a temperature as high as 90 degrees F. for some heats of rimmed steel, and at intermediate temperatures for semikilled grades. Some semikilled grades had transition temperatures as high as some of the rimmed steel heats.

Charpy impact tests have shown that the notch toughness of weld metal, including the heat-affected zone, is equal to or better than that of the base metal.

Tests of large tubular specimens ¾ inch thick under conditions of biaxial stress and −40 degrees F. temperature have produced brittle failures on semikilled ship plate exhibited as little plastic flow as has been observed on ship failures. The magnitude of stress at which such failures were produced was considerably below that of the uniaxial coupon stress.

SURVEY OF RESEARCH
Pertaining to
Investigation of Welded Ships

Line	Project	Location	Description	Percent Complete	Results
1	NRC-53	M.I.T.	Residual stress vs ballistic performance armor	100%	On 1" armor plate, residual stresses(1) are bi-axial stress through thickness approximately =0(2) are not influenced by different electrodes, (3) do not affect performance in explosion or ballistic shock test.
2	NRC-61	U.C.	Residual stresses - ship welding	100%	1" plate tests - Residual weld stresses are (1) high longitudinally (47,000 P.S.I. Tension), (2) low transversely (15,000 P.S.I. tension or compression), (3) unaffected by sequence in free assemblies, (4) reduced by (A) block welding, (B) controlled low temperature stress relief, (C) mechanical loading, (D) special peening.
3	NRC-65	W.P.I.	Crack sensitivity welds	100%	Stress patterns in 1/4" and 1/2" butt welds in ship plate using several types of electrodes and with various degrees of restraint have been determined, and indications of stresses necessary to produce cracking obtained.
4	NRC-72	M.I.T.	Ductility - welded members	100%	Temperature at which brittle fracture occurs in notched bend specimens varies with (1) the steel used, (2) whether welded or unwelded, (3) in welded specimens, whether as welded or polished.
5	NRC-74	U.C.	History - residual stresses welded ships	80%	(1) Average fore and aft stresses in deck plates (away from welds) are compressive and increase from 2,000 to 6,000 P.S.I. from sub-assemblies to completed liberty ships, (2) residual stresses in deck welds in old and new liberty ships and sub-assemblies show no significant differences. The magnitude of the longitudinal stresses are in the region of 35,000 to 40,000 P.S.I. in tension. (See also No. 18) (11 ships tested)

SURVEY OF RESEARCH
Pertaining to
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Line	Project	Location	Description	Percent Complete	Results
6	NRC-75	U.C.	Multi-axial stress ship steel - large tubes - welded	90%	A - on large welded tubes (20" dia., 10' L6) under bi-axial loading, (1) MEA sensible ductility is exhibited at room temperature irrespective of stress ratio and/or residual stress present. (2) At - 40°F brittle failures of the type encountered in ships occurred in as-welded tubes. B - on flat notched specimens under uni-axial loading, (1) cleavage fractures with low ductility occur on some ship plate at room temperature, (2) brittle fractures with ultimate average stress of 30,000 P.S.I. occur at + 32°F on some ship plate with certain notches.
7	NRC-77	I.I.T.	Multi-axial stress Ship steel - Small tubes	75%	Welded and unwelded tubes under bi-axial loading at room temperature exhibit good ductility. The true stress at fracture is somewhat lower than uni-axial test specimens.
8	NRC-82	CAL.TECH.	Steel dynamic loading (Specimens 0.300" dia.)	100%	S.A.E. 1015 hot rolled steel under dynamic loading (25' to 230') per second at room temperature shows 50% higher ultimate stress and energy absorption. No significant change in ductility.
9	NRC-86	LEHIGH	Weldability - Crack sensitivity - Steel	25%	(See No. 10)
10	NRC-87	BATTELLE	Metallurgy - Steel	25%	To date all work has been performed on H.T.S., but medium steel will also be investigated.
11	NRC-89	COWELL	Fatigue - Ship welds	10%	No results as yet - See No. 22
12	NRC-92-A	U.C.	Cleavage fracture flat plates - semi-killed ship steel	10%	Preliminary tests at low temp. and high stress gradients show low ductility of the order of 25 as in ships.

SURVEY OF RESEARCH
Pertaining to
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Line	Project	Location	Description	Percent Complete	Results
13	NRC-92-B	UC	Cleavage fracture ship steel - structural specimens	15%	A cargo hatch corner detail has been selected as the structural specimen to be used. Stress distributions around liberty ship hatch corner obtained during loading and at sea. Strain concentration of seven obtained at hatch corner in moderate sea.
14	NRC-93	U. ILL.	Cleavage fracture flat plates - rimmed and killed ship steel	10%	Internal notches terminating in jeweler's saw cut, and fatigue crack all produce cleavage fracture at same temperature, same energy absorption. Energy absorption and average ultimate stress drop rapidly as notch width to specimen width ratio increases.
15	NRC-94	CARNEGIE	Dev. new notch sensitivity test Ship steel	10%	No results as yet.
16	USMC - SCHUYLER		Hatch corner study - Full scale	60%	Extensive data being analyzed. Report in Preparation.
17	TMB		Hatch corner study (Photo - elastic models)	50%	No results available - difficulties have been experienced in building models.
18	TODD-HOUSTON		Stresses - Welded ships	75%	(1)Fore and aft stresses in deck plates (away from welds) in completed liberty ships average 8500 P.S.I. in compression. (2)The longitudinal residual weld stresses in the decks of completed liberty ships are in the region of 35,000 to 40,000 P.S.I. in tension (See also No.5) (Five vessels investigated)
19	BETH.-QUINCY		Stresses - welded ships and models	Unknown	Relaxation measurements on decks of completed liberty ships confirm findings of projects (5) and (18).

SURVEY OF RESEARCH
Pertaining to
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Line	Project	Location	Description	Percent Complete	Results
20	SUN-LINDE		Controlled low temperature stress relief	Unknown	Residual stresses in deck and shell plating welds can be reduced 50% or better by this method on butt welds.
21	CARNEGIE-ILL		Strength - welded ship joints	100%	Welds parallel to load depresse ductility but do not affect strength relative to coupon, cleavage fracture does not necessarily indicate lack of ductility, structural discontinuities are points of weakness even under static load. At corresponding temperatures notch-bar toughness of base metal, fusion zone and weld metal compare favorably at room temperature and 0°F, both as-welded and stress-relieved specimens exhibit good ductility, although ductility of the latter is somewhat better.
22	U.S.C.G.	U.ILL.	Fatigue-ship plate (notched)	10%	No results as yet
23	W.R.C.	I.I.T.	Fatigue - Biaxial-steel-specimens	15%	No results pertinent to investigation to date
24	TMB	WEMCO	Multi axial stress thin steel & copper tubes	100%	Results not pertinent to investigation.
25	N.Y.N.Y.		Steel specification improvement	50%	No results available as yet.
26	U.S.C.G.	BU.STDS.	Analysis - steel fractured vessel	Current	No results available as yet.
27	U.S.N.R.L.		Crack propagation - stresses for.	100%	Report requested.

SURVEY OF RESEARCH
Pertaining to
Investigation of Welded Ships

Line	Project	Location	Description	Percent Complete	Results
28	U.S.N.	BU.STDS.	Properties of ship steel	100%	(1) 18 sheared and strip mill steels from six sources tested. All met spec. AS-S-5. (2) Charpy V-notch tests show (a) rimmed steels in general show lower notch-toughness values than semi-killed steels (b) transition temperature to brittle fracture in line 21 occurs at higher temperature for rimmed steels (c) some heats of semi-killed steels no better than rimmed steels (d) normalizing tends to improve all values.
29	W.R.C.	CASE	Multi-axial tension - welded steel structures	0	No results as yet
30	W.R.C.	BU.STDS.	Residual stress & constraint welded structures	0	No results as yet
31	W.R.C.	M.I.T.	Residual stresses - welding	Unknown	No results as yet
32	W.R.C.	BKLYN. POLY.	Peening	Unknown	Insufficient data presented to properly justify conclusions.
33	U.S.C.G.	U.Ill.	Brittle fracture studies - notched ship plate	100%	Brittle cleavage fracture produced in ship plate at +32°F. with internal notch, after straining and aging. Average ultimate stress at fracture 35,000 P.S.I.
34	U.S.C.G.	MODEL BASIN	Tension tests notched plates - narrow bars	20%	On rimmed steel tested, (1) cleavage fracture occurs up to 90°F. (2) energy absorption decreases as temperature decreases (3) energy absorption is much greater with narrow notches.

Tests of large notched plates ¾ inch thick of ship steel under uniaxial tension load have produced brittle failures with low plastic flow at temperatures as high as 90 degrees F. At temperatures of 32 degrees F. brittle failure was produced in the case of one plate 72 inches wide at 29,000 psi. average stress in the net cross section.

It is believed that the lack of notch toughness at low temperatures, and the loss of strength and ductility under multiaxial stresses of shipbuilding steels is a prime factor in the failure of welded ships. It should be noted that these properties are not recognized in the existing specifications.

Investigations are now in progress to secure additional data on the strengths of different types of ship plate when subjected to multiaxial stresses at various temperatures. These studies include the testing of large tubular specimens under biaxial tension, of notched plate specimens and of full-scale portions of ship's structure.

3. Fabrication.—As mentioned in the introduction, the large part of the investigation covering this subject has thus far dealt with the matter of residual and locked-in stresses where the former are envisaged as being the by-product of welding unrestrained members, whereas the latter include also stresses resulting from other fabrication and assembly processes.

(a) Residual Welding Stresses.—It has been established that a reproducible pattern of high longitudinal tension stress and low transverse stress exists in all butt-welded joints in free ship subassemblies. The magnitude of these stresses in such subassemblies is not appreciably modified by welding sequence. Residual stresses are not affected by the type of electrode commonly used for ship fabrication nor by the use of austenitic 18-8 electrode.

The above must not be construed to mean that proper welding of erection

sequences are not important in preventing cracking and distortion during construction.

It has been determined that with a particular method of block-welding procedure in which block welds of not more than 5 inches in length are used a reduction in the resulting residual welding stress of approximately 50 per cent is possible. It should be noted, however, that this method requires that the temperature of the welded block be 125 degrees F. or less before the next succeeding block is deposited. The method appears to have merit for special application, but because of the obvious loss of welding time does not appear suitable for general use in ship welding.

The residual welding stresses may be reduced 50 per cent or more in case of simple butt-welded joints in free subassemblies, by the application of a controlled low-temperature stress-relieving treatment, producing a temperature differential between the weld and base metal. Its effectiveness in geometrically more complex joints or structures has not been so far demonstrated.

Peening the last pass of the welds will also materially reduce the magnitude of residual welding stresses. On the basis of investigations performed, it does not appear that peening other passes than the last will affect reductions of final residual stresses. This statement, however, must not be construed to mean that peening intermediate and root passes is not helpful in preventing weld cracking and in controlling distortion.

It has been found that residual welding stresses can be relieved by the application of external load causing plastic flow of the weld metal and adjacent area. Conditions of external restraint tending to inhibit plastic flow in the weld area will reduce the amount of stress relief taking place. Such conditions apparently exist in varying degrees on board ship because on eight Liberty ships investigated to date the residual stresses in the deck joints abreast of No. 3 hatch were not "worked out" or even reduced significantly after considerable service. A small reduction of residual stress was observed on two tankers subjected to severe hogging and sagging tests, but the magnitude of reduction was very much less than what could be expected in unrestrained welds subjected to the same unit loadings. Preheating ship steel up to 375 degrees F. does not achieve significant reductions in residual welding stresses.

Tests of large tensile specimens of ship steel up to 30 square inches in cross-sectional area were made in order to compare "as-rolled" plate with longitudinally welded plates both in the "as-welded" and stress-relieved conditions. Those tests showed that the elongations of "as-welded" plates were somewhat less than those obtained in either "as-rolled" plate or welded plate which had been stress relieved. However, the large amount of plastic flow which preceded failure in the "as-welded" plates does not in any way duplicate the brittle fractures with barely measurable plastic flow which have been characteristic of the ship failures.

Tests of large tubes of both ½- and ¾-inch thick ship plate, in both stress-relieved and "as-welded" conditions, subjected to biaxial tension stresses again indicated ability of plate and welds to undergo large plastic flows irrespective of the presence of residual welding stresses.

In general, it may be concluded that the contribution of the residual welding stresses to the failure of welded steel ships has not yet been fully determined. Preliminary results of all investigations of this subject indicate to date that residual stresses do not contribute to the failure of welded structures except possibly under some special conditions of stress, inhibiting shear flow.

Some indications exist that the effect of metallurgical changes caused by welding process is more important in the properties of welded structures than that of residual welding stresses.

(*b*) *Locked-In Stresses.*—Considerable research is now in progress investigating the magnitude of the locked-in stresses which are defined as all stresses resulting from fabrication and assembly processes.

Up to the present time no tensile locked-in stresses have been observed in deck plate of approximately 30 ships investigated by three independent agencies and representing ships built in a variety of shipyards and with a

number of erection sequences. The locked-in deck plate stresses are of the order of 4000–8000 psi. in compression in the fore and aft direction.

Investigation of locked-in stresses is being continued to include effect of unusual climatic conditions.

III. Conclusions.

On the basis of the data available to date, the following conclusions are drawn:

1. Residual welding stresses do not contribute materially to the failure of welded structures.
2. Locked-in stresses in the deck plating (away from welds) of completed ships are generally compressive and of low magnitude (4000–8000 psi.).
3. Residual welding stresses in completed vessels are not appreciably reduced by normal service.
4. Lack of notch toughness at low temperature and loss of strength and ductility under multiaxial stresses, of steels used in ship building is a prime factor in the failure of welded ships.
5. Large tubular specimens of ship steel, with and without welds, tested under biaxial tension and especially at low temperature, show great reduction in strength and ductility as compared with results from usual tensile tests at corresponding temperatures. At −40 degrees F. lack of plastic flow was comparable to that found on ship fracture.
6. Large notched specimens of ship plate tested at 32 degrees F. produced brittle failures at half the nominal strength with lack of plastic flow comparable to ship fractures.
7. Very high stress concentrations exist in the hull structure of ships. A strain concentration of 7 has actually been measured on a cargo hatch corner, the vessel being at sea.
8. Welding sequence in general has no effect upon the magnitude of residual welding stresses in free subassemblies.
9. Residual welding stresses may be reduced by peening the last pass of manual welds.
10. Residual stresses are not reduced by preheating up to 375 degrees F.

It must be reiterated that the above conclusions are based on data produced to date. Additional data which are expected shortly from the research now under way may necessitate revisions or modifications of some of these conclusions.

RADAR COUNTERMEASURES.

This article is a simple explanation of the principles of radar countermeasure equipment for the layman. It is reproduced from the January 1946 issue of "Product Engineering."

"The new eyes which radar has supplied can sometimes be blinded by new scientific developments."—Dr. Vannevar Bush.

In a joint release by the Army, Navy and the Office of Scientific Research and Development, another war secret—electronic warfare—is revealed. Overshadowed only by the weapon of radar itself, the imagination is staggered by the vast amount of energy, electromagnetic and human, expended in blotting out the enemy's radar sets.

Several weaknesses of radar lent themselves to exploitation, both by the Germans and the Allies. An examination of these weaknesses will prove useful in discussing the counter-radar devices which were developed during the war.

Radar stations sent out radio impulses of tremendous strength; all that is needed to detect these signals is a special receiver which can tune to the extremely short wavelength used by radar. This represents the first weakness of radio location. Second, a radar set betrays not only its existence, but also its exact location. A radio direction finder makes it possible to determine the direction from which the signal is coming.

A third weakness of radar sets is the fact that the echo returned from most targets is weak in strength. The sound returned from the cliff is many times weaker than the man's original shout. A fairly weak noise, therefore, would suffice to cover up the echo. A second man, standing on the cliff and shouting continuously, would prevent the first man from hearing his own echo.

Radars can be blinded in the same way. It is only necessary to provide the target with a device which sends out a radio signal capable of covering up the signals reflected back to the radar by the target. This process is known as electronic jamming. Because each radar set operates on a particular frequency channel, it is necessary that the jammer—which is fundamentally a small radio transmitter—be tuned to that same channel.

A practical radar jammer consists of a tunable radio transmitter provided with a type of modulation which is especially suited to drowning out radar echoes. Any home radio owner who uses an electric razor has a good idea of what such interference means. It has been found that the most effective radar jamming signal is simply a hissing noise similar to the background noise heard in sensitive radio receivers when no program is being received. Such a signal is said to have a "random noise modulation."

When picked up on a radio receiver equipped with a loudspeaker, a noise jamming signal sounds like a hiss. A radar, however, presents the information it received not aurally but visually. Signals appear as patterns on the face of a cathode-ray tube. As seen on this tube the "noise" looks like many fine blades of grass moving about in a random fashion. Echoes from airplanes, which are usually displayed as vertical spikes on the radar scope, simply disappear and become lost in the "grass."

WINDOW.

A further weakness of radar sets is the circumstance that they cannot distinguish the nature of small targets. One small object, capable of returning an echo, looks to a radar just about the same as another. To a radar, an airplane or a ship is a small object. It has been found that a number of thin metallic strips, cut to a length proportional to the wave length used by a radar, can return a remarkably strong echo to that equipment. In fact, several thousands of these thin metallic strips, packaged in a small bundle weighing less than 2 ounces, will give a radar echo signal equivalent to one bomber, when the strips are ejected from a plane and allowed to fall freely through the air.

The phenomenon is one of resonance. The metallic strips, designated by the code name "Window," are resonant at the frequency of the radio waves sent by radar; in this way a relatively small number of strips can return an echo equal to that from a large metal object such as an airplane.

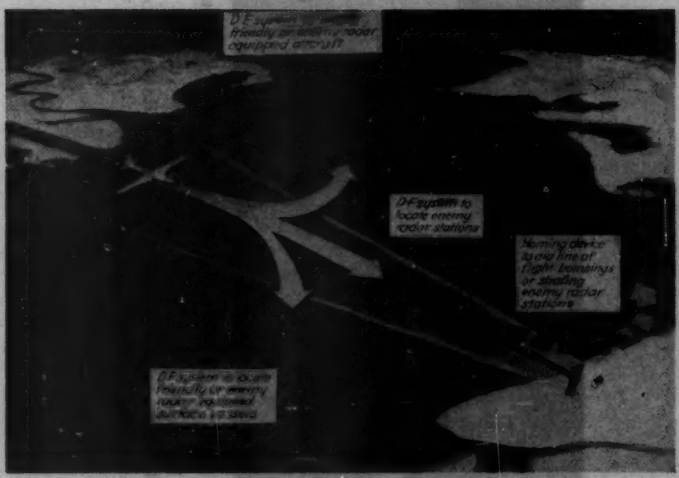
If a number of Window packets are dropped out of a plane in succession, a trail is produced in which a radar can no longer distinguish a real target. The echo from an aircraft is simply lost among the echoes from the Window. It is much as if the planes were being concealed by a smoke screen of metallic foil.

"TUBA."

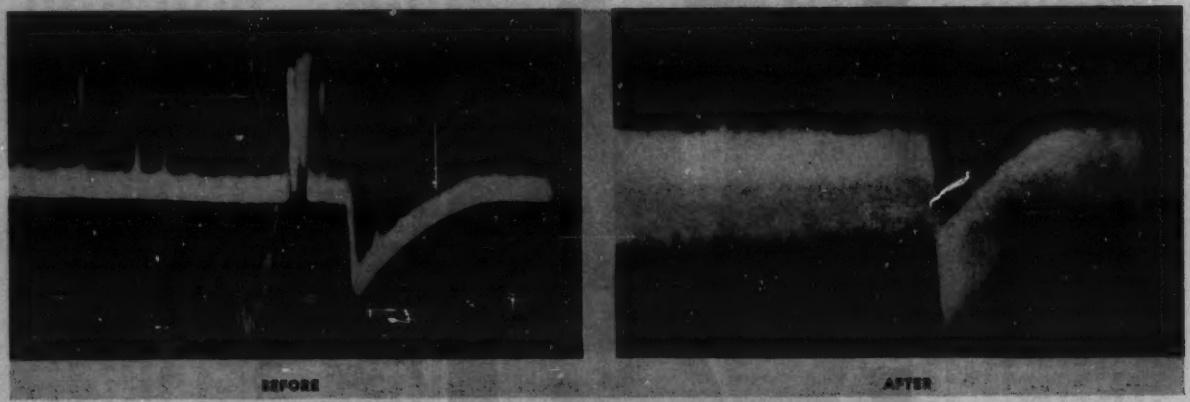
Like radar itself, radar countermeasures were developed by many cooperating agencies. Most of the research on this development, however, was done at the Harvard Radio Laboratory, under Division of 15 of the National Defense Research Committee, and was financed by government funds through the Office of Scientific Research and Development.

One of the most ingenious countermeasures developed by the Harvard Laboratory was a device known as "Tuba"—a tremendously powerful jamming transmitter developed for use against German night fighters. In addition to its countermeasures applications. It was certainly one of the outstanding individual scientific achievements of the war.

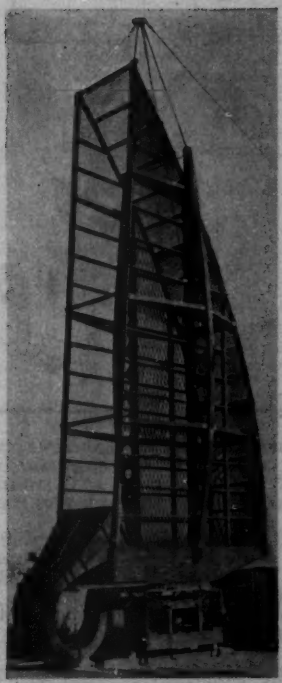
The problem was to create a jamming device to blind the German night fighters, which in 1942 took a heavy toll of British night bombers. The German fighters used an air-borne interception radar known as "Lichtenstein" for


DF system to locate enemy radar stations
Homing device to give line of flight bearings of shooting enemy radar stations

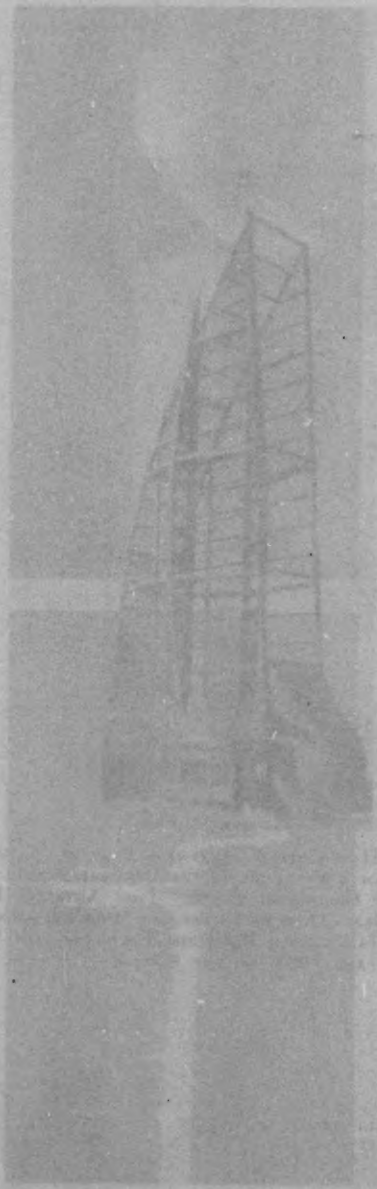
ILLUSTRATED HERE IS THE OPERATION OF ONE OF THE MANY RADAR DIRECTION FINDING SYSTEMS, WHICH WERE USED IN FERRETS AND OTHER AIRCRAFT FOR ACCURATELY DETERMINING THE LOCATION OF A CONCEALED ENEMY RADAR STATION. AS A DIRECTION FINDER, IT WAS USED ALSO FOR NAVIGATION AND HOMING ON OUR OWN RADAR SYSTEMS.

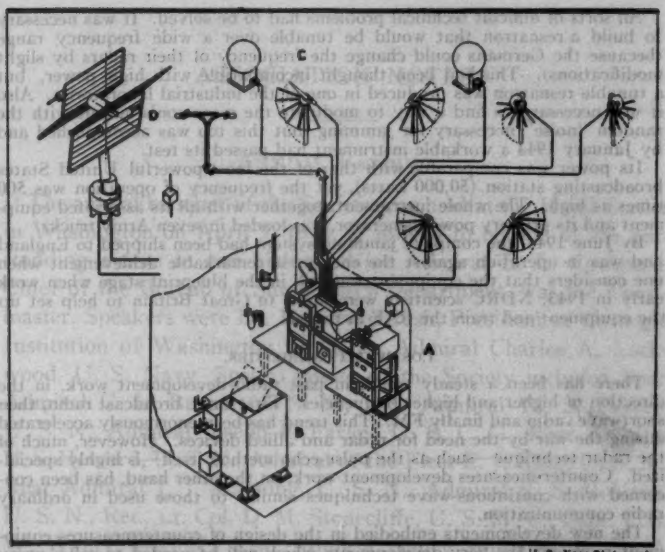


These Photos Show What Havoc "Jamming" Raises on a Radar Indicator. At Left, a Radar Scope Picks Up a Distant Target, With the "V" Notch Showing the Range of the Object. At Right, the Radar Installation Has Been Jammed by a "Tuba" Set Falling Strips of "Window," or Other Countermeasure, and the Image on the Enemy Radar Scope Is Confused.



THIS ODD-LOOKING "HALF-CHEESE" ANTENNA, PART OF "TUBA," IS DESIGNED TO GIVE A BEAM VERY SHARP IN THE VERTICAL PLANE, AND RELATIVELY BROAD IN THE HORIZONTAL PLANE. THIS ANTENNA IS UNIQUE IN THAT IT WILL OPERATE OVER AN UNUSUALLY WIDE FREQUENCY RANGE. THE "HALF-CHEESE" IS REALLY A REFLECTOR, EXCITED BY THE WAVEGUIDE AND HORN AT THE BOTTOM.





U. S. Navy Photograph

TYPICAL RADAR COUNTERMEASURE INSTALLATION ABOARD SHIP: *A*, EQUIPMENT FOR PICKING UP, ANALYZING AND DETERMINING DIRECTION OF ENEMY RADAR PULSES; *B*, JAMMING TRANSMITTER; *C*, AND *D*, ANTENNAS USED IN LOCATING AND JAMMING ENEMY RADAR.

close-range location of their targets. Against them the British found it impractical to use jammers carried in their bombers, because the jammer itself provided a signal which the German fighters could use to locate the bomber. A radio signal, including a jamming one, betrays the direction from which it comes and even though a jammer might blot out a German scope, making it impossible to find the range, the German could find the bomber simply by following the signal in.

But the German night fighters usually did not reach their prey until after the British bombers were flying home from their mission. Someone suggested why not set up a very high-powered jammer in England to blind the German fighters' radar as they flew toward it in pursuit of the homeward bound bombers? It would be a blinding beam "shining" in the German "eyes" (i.e., their radar antennas)—through which the bombers could fly to their bases in safety.

A jammer of this sort obviously would require enormous power. It was calculated that it would need power a thousandfold more than any previously attained in the frequency range of operation involved, which in itself was 10 times higher than that used for frequency modulation and television.

It appeared possible to solve the power problem by means of a remarkable vacuum tube, developed in the United States, known as the "Resnatron." This NDRC development, sponsored by the Signal Corps, was so promising that the British immediately placed a lend-lease order in the United States for a complete jamming system based on its use.

Since the experimental model used a huge parabolic antenna, the project was promptly nick-named "Tuba," to distinguish it from smaller projects already known as "Piccolo," "Flute," and the like.

All sorts of difficult technical problems had to be solved. It was necessary to build a resnatron that would be tunable over a wide frequency range (because the Germans could change the frequency of their radars by slight modifications). This had been thought incompatible with high power, but a tunable resnatron was produced in one of the industrial laboratories. Also it was necessary to find a way to modulate the resnatron's output with the random "noise" necessary for jamming, but this too was accomplished and by January 1944 a workable instrument had passed its test.

Its power was comparable with that of the most powerful United States broadcasting station (50,000 watts), yet the frequency of operation was 500 times as high. The whole instrument, together with all its associated equipment and its primary power generator, was loaded in seven Army trucks.

By June 1944, the complete jamming system had been shipped to England and was in operation against the enemy—a remarkable achievement when one considers that the equipment was still in the blueprint stage when work early in 1943, NDRC scientists were flown to Great Britain to help set up the equipment and train the RAF in its use.

Postwar Possibilities.

There has been a steady trend, in past radio development work, in the direction of higher and higher frequencies. First came broadcast radio, then shortwave radio and finally FM. This trend has been enormously accelerated during the war by the need for radar and allied devices. However, much of the radar technique—such as the pulse-echo method itself—is highly specialized. Counter-measures development work, on the other hand, has been concerned with continuous-wave techniques similar to those used in ordinary radio communication.

The new developments embodied in the design of countermeasures equipment represent the very developments which will be needed to solve many postwar problems and to make applications possible.

Basically, much countermeasures research was directed toward the improving and development of radio transmitters and receivers of a type very similar to those which will be used in postwar FM, television, and radio relay transmission.

ASSOCIATION NOTES.

Annual Banquet.

The annual banquet of the Society was held at the Hotel Statler in Washington on April 5, 1946. It proved to be one of the outstanding events in our history: Vice Admiral E. L. Cochrane, Chief of the Bureau of Ships, Navy Department, was the Toastmaster. Speakers were Dr. Vannevar Bush, President of Carnegie Institution of Washington, and Vice Admiral Charles A. Lockwood, U. S. Navy. Special guests of the Society included Rear Admiral C. L. Brand, U. S. N., Vice Admiral W. S. Farber, U. S. N., Admiral Joseph F. Farley, U. S. C. G., Rear Admiral H. S. Howard, U. S. N., Admiral of the Fleet E. J. King, U. S. N., Rear Admiral J. J. Manning, U. S. N., Admiral S. S. Robison, U. S. N., Ret., Lt. Col. D. M. Stonecliffe, U. S. M. C., Capt. J. B. W. Waller, U S N., Rear Admiral Henry Williams, U. S. N.

The text of the speeches will be found in this issue of the Journal.

Prize Essay: The prize offered by the Society for the best article submitted by a Naval Reserve Officer during 1945 on the general subject of Engineering as Seen by a Naval Reserve Officer was awarded to Commander Donald L. Herr, U. S. N. R. It is published in this issue of the Journal.

Change in Council: Lieut. Commander Kenneth H. Beeson, U. S. N. R., resigned as a member of the Council of the Society consequent on his detachment from duty in Washington. The Council has appointed Captain Robert E. Coombs, U. S. C. G. R., to fill the vacancy.

Membership: The following have joined the Society since the publication of the February, 1946, Journal:

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